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Report 2326

PERFORMANCE OF INDUSTRIAL-TYPE ENGINES
IN MILITARY EQUIPMENT USING SYNTHETIC CRANKCASE OILS

by
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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number) → The investigation was to determine the possibility of eliminating crankcase oil changes in engines used in Military equipment. Based on the results, it appears that an extended oil change interval can be used which would result in significant savings. | | |

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SUMMARY

Recent claims by industry regarding the use of synthetic oils for engine crankcase lubrication necessitated an investigation of the possibility of eliminating crankcase oil and filter changes in Military engines and equipment. Such claims state that synthetic engine oils outperform conventional oils by providing better high-temperature stability, reduced oil consumption, better oil-pressure retention, and reduced engine wear.

Investigation of the industry claims was accomplished under a two-phase test program using synthetic crankcase oils to effect a "no drain add makeup oil" crankcase servicing procedure for fielded Military equipment. Phase I consisted of testing the small bore 1.5-, 3-, and 6-hp Military Standard Gasoline Engines and Phase II consisted of testing the DOD Diesel Engine-Driven Generator family 5- to 100-kW sets.

Phase I was initiated in 1977 and a total of 11,653 hours was accumulated on the gasoline engines using two different synthetic oils. The engines were run for 1500 hours without an oil change. Chemical and spectrometric analyses were obtained from samples; however, these data were not plotted because of the high oil consumption. Oil consumption using synthetic oil was about twice that of conventional oils making it decidedly uneconomical and unworthy of serious consideration. No excessive wear or detrimental effects were observed from the use of synthetic oils during this testing.

Phase II was initiated in 1978 and included 12 production generator sets utilizing 6 different diesel engine models and 2 different synthetic oils. Although some sets ran for 5000 hours without an oil change, most required a change at about 3400 hours. The reason for the oil change was the loss of the alkaline reserve, not viscosity or wear metal levels. A total of 55,100 hours of engine operation was accumulated. Following completion of the tests, all engines were torn down for inspection. No excessive wear was detected that could be attributed to use of synthetic oil.

Based on these test results and the average usage rate per year, the oil change interval for the diesel sets using synthetic oils could be extended to a 1000-hour or 1-year change interval. This policy as shown in the economic analysis would yield almost a million dollars per year savings over current drain intervals. This does not include the savings in man-hours or the logistics of stocking less oil.

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PREFACE

Gene H. Austin, Support Equipment Branch, Engineering Division, Electrical Power Laboratory, compiled the final report.

The inspections and the evaluation of wear patterns on critical engine parts were made by Thomas Bowen, Energy and Water Resources Laboratory.

The test data were collected and compiled by Lewis Cheek, Product Assurance and Testing Directorate.

The analyses and interpretation of the oil sample data were performed by Basil Zanedis, Material Technology Laboratory.

The day-to-day monitoring of the test program was performed by Ernest Fitzgibbons, Support Equipment Branch, Engineering Division, Electrical Power Laboratory.

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PERFORMANCE OF INDUSTRIAL TYPE ENGINES IN MILITARY EQUIPMENT USING SYNTHETIC CRANKCASE OILS

I. INTRODUCTION

1. Statement of the Purpose. The purpose of this test program was to determine if a "no drain add makeup oil" concept for gasoline and diesel engines used by the Army is feasible without affecting the reliability and life cycle of the engine in the DOD Family of Gasoline and Diesel Engine-Driven Generator Sets.

2. Background. A Production Engineering Measures (PEM) project was submitted and approved in 1977 for a two-phase test program to evaluate synthetic crankcase oils in gasoline and diesel engines. The DOD family of generator sets was chosen because the generator offers a ready means of loading the engine and provides an economical means of conducting the tests. Additionally, baseline data had already been established on the DOD family of generator sets using conventional MIL-L-2104C oils.* This baseline serves as a basis of comparison in both performance and in making an economic analysis. The 200-kW set was not tested because a baseline had not been established using MIL-L-2104C oil and because of the high cost of fuel.

II. PROCEDURE

3. Approach.

a. Phase I. Phase I was conducted from December 1977 to May 1978. Twelve engines (four each 1.5-, 3-, and 6-hp) were used for the performance and endurance testing. The engines were tested for 1500 hours each. Tests were conducted by the Electrical and Mechanical Division, Product Assurance and Testing Directorate, MERADCOM.

b. Phase II. Phase II was conducted from December 1978 to September 1979. Twelve production DOD diesel engine-driven generator sets powered by six different diesel engines were subjected to long-term endurance tests. Total test time for Phase II was 55,100 hours. Tests were conducted by the Electrical and Mechanical Division, Product Assurance and Testing Directorate, MERADCOM.

c. Test Units and Test Time. The types and sizes of engines are shown in Table 1 for Phase I. The types and sizes of generator sets, the makes and models of the diesel engine powering each set, and the accumulated number of hours for each set are included in Table 2 for Phase II.

* Chester R. Gurski, John W. Dreger, and Ernest Fitzgibbons, EXTENDED OIL-CHANGE AND OIL-FILTER-CHANGE INTERVALS FOR DOD 5- TO 200-KILOWATT DED GENERATOR SETS, MERADCOM Report 2234 (March 1978).

Table 1. Phase I Gasoline Engines

| Power (kW) | Frequency (Hz) | Engine Serial Number | Engine Model | Oil Type | Hours |
|---------------|-------------------|-------------------------|--------------|----------|-------|
| .5 | 60 | M041390 | 1A08 | C | 1500 |
| .5 | 60 | M041324 | 1A08 | C | 1500 |
| .5 | 60 | M040306 | 1A08 | D | 1500 |
| .5 | 60 | M041348 | 1A08 | D | 1153 |
| 1.5 | 60 | N85753 | 2A016 | C | 1500 |
| 1.5 | 60 | N85426 | 2A016 | C | 1500 |
| 1.5 | 60 | N85531 | 2A016 | D | 1500 |
| 1.5 | 60 | N85719 | 2A016 | D | 1500 |
| 3 | 60 | J97508 | 4A032 | C | 1500 |
| 3 | 60 | J103367 | 4A032 | C | 1500 |
| 3 | 60 | J103290 | 4A032 | D | 1500 |
| 3 | 60 | J103361 | 4A032 | D | 1500 |

Table 2. Phase II Diesel Engine-Driven Generator Sets

| Power (kW) | Frequency (Hz) | DOD Model | Set Serial Number | Engine Model | Oil Type | Hours |
|---------------|-------------------|--------------|----------------------|--------------|----------|-------|
| 5 | 60 | MEP002A | E200297 | Onan DJE | A | 5000 |
| 5 | 60 | MEP002A | E200937 | Onan DJE | B | 4300 |
| 10 | 60 | MEP003A | E200052 | Onan DJF | A | 4700 |
| 10 | 60 | MEP003A | E200053 | Onan DJF | B | 4800 |
| 15 | 60 | MEP004A | R220030 | White | A | 4800 |
| 15 | 60 | MEP004A | R221277 | White | B | 4400 |
| 30 | 60 | MEP005A | R251233 | White | A | 5000 |
| 30 | 60 | MEP005A | R251245 | White | B | 4900 |
| 60 | 60 | MEP006A | F201243 | A.C. 3500 | A | 4600 |
| 60 | 60 | MEP006A | F201254 | A.C. 3500 | B | 4700 |
| 100 | 60 | MEP007A | U200709 | Cat D333T | A | 4600 |
| 100 | 60 | MEP007A | U200697 | Cat D333T | B | 4300 |

4. Description of Test Program.

a. Phase I. Phase I consisted of performing both a chemical and a spectrometric analysis of oil samples taken at 200-hour points for the model 1A108 engine and at 100-hour points for the models 2A016 and 4A032 engines for the 1500-hour duration.

b. Phase II. Phase II consisted of performing both a chemical and a spectrometric analysis of oil samples taken at 100-hour points for the duration of the 5000-hour test. All other engine and generator set maintenance and servicing were performed in accordance with the technical manuals applicable to each size set.

c. Receiving Inspection. Each generator set was inspected and checked for proper operation. Engines were changed in the four 15- and 30-kW sets to evaluate the commercial version of the White D198ER and D298ER engines. These commercial engines are identical to the ones being used in the sets except that the bore size has been increased from 3.750 to 4 inches. Log books were maintained for each set and included an account of set operations, servicing, and maintenance performed; failures; and all other pertinent information relating to operation. Notations were included regarding fuel type and sulfur content, identification of type synthetic oil used, and fuel and oil consumption.

d. Preparation of Sets for Test. The generator sets were prepared for operation in accordance with the procedures contained in the applicable technical manuals. An external fuel supply line was connected to the set. An oil sampling valve with the necessary plumbing was installed on each engine in the lube oil gallery to provide a means for taking oil samples during the course of the endurance test.

e. Instrumentation. Various temperature, pressure, and electrical parameters were measured in order to determine performance of the engine and the generator. All instruments were of laboratory grade and were maintained under a periodic calibration program.

f. Fuel and Lubricants. The fuel used for Phase I was unleaded gasoline conforming to Federal Specification VV-G-1690B, and the fuel used for Phase II was grade DF2 diesel fuel conforming to Federal Specification VV-F-800B. The lubricating oils used were:

| | OIL C | OIL D |
|-----------|--|-------------------------------------|
| PHASE I: | Ester Base | Ester Base |
| | OIL A | OIL B |
| PHASE II: | Alkylated Benzene with Petroleum Base | Polyalpha Olefin with Ester Base |

Phase I oils were SE/CC-quality-level products qualified under Military Specification MIL-L-46152. The Phase II oils were SE/CD-quality-level oils.

g. Pre-Endurance Operation. All starting and operating procedures were in accordance with the applicable technical manuals except for oil changes and oil filter changes.

h. Endurance Tests. All tests were conducted as follows:

Phase I:

Check Test and Run-In

Maximum Power Test — Pre-Endurance and Post-Endurance

Endurance Test — 1500 Hours (See Table 3)

Teardown and Inspection

Table 3. Endurance Load-Cycle Schedule Phase I and Phase II

| Step Number | Total Time (Hours) | Load Condition |
|-------------|--------------------|-----------------|
| 1 | 24 | 50% Rated Load |
| 2 | 4 | 0% Rated Load |
| 3 | 24 | 100% Rated Load |
| 4 | 24 | 25% Rated Load |
| 5 | 24 | 75% Rated Load |

Phase II:

All tests were conducted in accordance with MIL-STD-705 as follows:

METHOD

- 640.1c Pre-Endurance Maximum Power Test**
- 670.1a Pre-Endurance Fuel Consumption Test**
Endurance Test (See Table 3)
- 640.1c 500-Hour Maximum Power Test**
- 640.1c 1000-Hour Maximum Power Test**
- 640.1c 1500-Hour Maximum Power Test and Fuel Consumption Test**
- 640.1c 2000-Hour Maximum Power Test**
- 670.1a 2000-Hour Fuel Consumption Test**
- 640.1c 2500-Hour Maximum Power Test**
- 670.1a 2500-Hour Fuel Consumption Test**
- 640.1c 3000-Hour Maximum Power Test**
- 640.1c 3500-Hour Maximum Power Test and Fuel Consumption Test**
- 640.1c 4500-Hour Maximum Power Test and Fuel Consumption Test**
- 640.1c Final Maximum Power Test**
- 670.1a Final Fuel Consumption Test**

The following logbook entries were made during each shift as applicable:

Date, shift hours, and total elapsed test hours all adjustments were made.
Information regarding scheduled maintenance performed.
Title and test method number of all performance tests performed.
Explanation of all shutdowns.
Results of periodic, visual inspections.
All failures which occurred and repair parts used.
Oil added.

i. **Oil samples.** Each oil sample was identified with the following information on the label:

Generator set serial number.
Total number of hours that oil was used.
Total number of engine operating hours.
Pertinent servicing, maintenance, failure, and parts replacement since last oil sample was taken and amount of oil added if any since last sample.

j. **Scheduled Maintenance.** Maintenance was performed in accordance with Table 4 and the following maintenance schedules:

Table 4. Servicing and Adjustment Schedule -- Phase I

| Before Test | Hours Between Service Periods During Test | Item |
|--------------------|--|---|
| X | 8 | All maintenance, such as tightening and retorquing nuts, bolts, and screws. |
| | | Parts, components, and accessories replacement or any major maintenance that requires removal of other components, accessories, or shrouding, such as oil pans, cylinder heads, and connecting rods shall be recorded with cause determination. |
| X | a | Cleaning, regapping, or replacing spark plugs. |
| X | b | Servicing fuel filter. |
| X | 250 | Checking compression pressures. |
| X | 8 | Adding lubricating oil. |
| X | 8 | Adjusting carburetor. |
| X | b | Cleaning carburetor. |
| X | 8 | Adjusting govenor (normal speed adjustment). |
| X | c | Changing lubricating oil. |
| X | c | Changing lubricating oil filter element. |
| X | 100 | Servicing air cleaner. |
| X | a | Adjusting and dressing breaker points. |
| X | a | Adjusting ignition timing. |
| X | b | Cleaning combustion chamber and manifolds. |
| X | a | Replacing breaker points. |
| X | a | Replacing condensor or coil. |

Table 4. Servicing and Adjustment Schedule – Phase I (Cont'd)

| Before Test | Hours Between Service Periods During Test | Item |
|-------------|---|---------------------------------|
| | 500 | Retorque head nuts (250 in-lb). |
| | b | Gasket replacement. |

a As required by apparent misfire or loss of power.

b If required.

c To be determined by oil analysis.

Phase II Maintenance Schedule 5- Through 100-kW

8-Hour Check:

- Perform visual inspection.
- Check oil level; add oil when the level is at or below the "add oil" mark. Secure 5- and 10-kW. Check oil level after 5 minutes.
- Check battery level.

100-Hour Check:

- Perform visual inspection.
- Remove one 1-ounce size oil sample.
- Remove one 4-ounce size oil sample for the 5- and 10-kW size sets on even 100-hour points; i.e., 200, 400, 600 etc.
- Remove one 8-ounce size oil sample from the 15- through 100-kW size sets on even 100-hour points; i.e., 200, 400, 600, etc.
- Check oil level; add oil to return level to "full" mark on dip stick.
- Check shutter assembly for proper operation.
- Check V-belts for proper condition if applicable.
- Replace air cleaners on 15- through 100-kW size sets.

- Check coolant level.
- Clean crankcase breather.
- Clean fuel transfer pump filters.

NOTE: On 5- and 10-kW:

- Adjust governor and throttle linkage if necessary.
- Clean dust cap on air cleaner.

**500-Hour Service to be Performed at
1000, 1500, 2000, 2500, 3000, 3500, 4000, 4500, and 5000 Hours:**

- Change fuel filters.
- Check and adjust valve tappet clearance.
- Remove oil samples (see 100-hour service sheet).
- Check oil level and return to full mark on dip stick.
- Check shutter assembly for proper operation.
- Clean fuel pump transfer pump filters.
- Change air cleaners on 5- and 10-kW size sets.
- Clean crankcase breather.
- Conduct a short-term 608.1 and a maximum power test (640.1 or 640.3).

1000-Hour Service to be Performed at 1500, 2500, 3500, and 4500 Hours:

- Perform visual inspection.
- Remove one 1-ounce size oil sample.
- Check oil level and return to full mark on dip stick.
- Check shutter assembly for proper operation.

- Replace all belts.
- Change fuel filters.
- Clean crankcase breather.
- Clean fuel pump transfer pump filters.
- Check and adjust valve tappet clearance.
- Check compression pressures.
- Check injectors for proper operation.
- After above test, conduct a short-term 608.1 and a maximum power test (640.1 or 640.3).
- Perform 2-hour fuel consumption test.

2500-Hour Service to be Performed at 2500 and 5000 Hours:

- Check injector for proper operation.
- Obtain compression pressures.
- Perform 500-hour service.

5. Description of Oil Analyses and Sampling Procedures.

a. Oil Analysis. A description of the chemical and spectrometric oil analyses performed during this program is included in Tables 5 and 6. The warning limits outlined for the spectrometric analysis were established through coordination with the respective engine manufacturers. The manufacturers cautioned that the wear-metal concentrations could vary between engines depending upon basic internal engine construction, type of service (i.e., duty cycle), and the regularity with which routine maintenance is performed.

Table 5. Chemical Oil Analysis

| Chemical Property | Test Methods | Significance | Precautionary Limits |
|----------------------------------|--------------|---|---|
| Viscosity | ASTM-0445 | (1) Establishes viscosity index. (2) An indication of oxidation can be summarized by observing successive differences between viscosity at 100° F and 210° F. | Limit has been reached when viscosity at 210° F either increases in value to the next higher SAE grade (maximum oxidation) or decreases in value to the next lower SAE grade (maximum fuel dilution). |
| Total Acid and Total Base | ASTM-0664 | The total acid number (TAN) to a degree defines the buildup of acid materials in oil resulting from combustion and oil oxidation, while the total base number (TBN) relates to the oil alkaline reserve provided to combat acidic products. Decreasing TAN is indicative of additive depletion. | TAN limit has been reached when TAN increases two whole numbers from that value recorded for new oil (batch sample). TBN limit has been reached when TBN decreases to one-half original value of new oil (batch sample). |
| Insolubles Percent Pentane | ASTM-2276 | In principle, the arithmetic difference between the Pentane and Benzene insolubles is a measure of oxidation. | Pentane: When percentage of Pentane insolubles reaches 1.50 percent. |

Table 6. Spectrometric Oil Analysis.

| Allis Chalmers Model No. 3500 | | | Caterpillar Model No. D333T | | |
|-------------------------------|-------------------------------------|------------------------|--|------------------------|--|
| Metal | Parts | Warning Limit (p/m) | Parts | Warning Limit (p/m) | |
| Aluminum | Pistons Blowers Bearings | 80 | Pistons Main Bearings Rod Bearings Oil-Pump Bushing Timing Gear Bushing Crankshaft Thrust Bushing Fuel-Pump Lifter | 18 | |
| Tin | Bearings | 30 | Bearings | 40 | |
| Chromium | Piston Rings Shafts | 50 | Piston Rings | 20 | |
| Lead | Bearings | 60 | Overlay on Main and Rod Bearings | 75 | |
| Silicon | Air-Cleaner Element | 30 | Air-Cleaner Element | 30 | |
| Iron | Piston Rings Cylinders Shafts | 125 | Crankshafts Cylinder Liners Camshaft Connecting Rod and Gears | 120 | |
| Copper | Bushings Bearings | 60 | Rocker-Arm Bushings Wrist-Pin Bushings Timing-Gear Thrust Washer Governor Bushing Fuel-Transfer-Pump Bushing Oil-Pump-Drive Thrust Washer | 30 | |

b. Sampling Procedures.

(1) One 4-oz size sample was taken for chemical analysis after the first 100 hours of engine operation and after each 200 hours of operation thereafter in the 5- and 10-kW generator sets. One 8-oz sample was taken after the first 100 hours of engine operation and after each 200 hours thereafter for the 15- through 100-kW generator sets. One 1-oz size sample was taken for spectrometric analysis after each 100 hours of engine operation.

(2) **Spectrographic Procedures.** The Jarrell-Ash Model 750 Atom Counter, Atomic Emission, Direct-Reading Spectrometer was used in the analysis. The electrodes used were National, Disc Type L 4075 AGKSP $\frac{1}{2}$ -inch diameter, 1/8-inch thick, Counter Electrode Type I.3957 AGKSP $\frac{1}{4}$ -inch rounded upper 1/16-inch radius. Maximum impurity of the electrodes: Aluminum 0.5 p/m, iron 0.4 p/m, copper 0.5 p/m, silicon 2.4 p/m. The instrument was standardized with Continental Oil Company CONOSTAN Type D-20 metallo-organic standards in the following concentrations: 0, 10, 30, 50, 100, and 300 p/m ranges.

III. TEST RESULTS

6. Oil Analyses Test Data. During this program, the results of the chemical and spectrometric oil analyses were tabulated and plotted by use of a Cal Comp Plotter. This computer printout technique greatly simplified making decisions as to oil condition. These tabulations are given in the Appendix to this report.

7. Oil Consumption Data. Oil consumption data are given in Table 7.

8. Discussion of Oil Analyses. Results are discussed in the following paragraphs for Phase I and Phase II and are presented graphically in the Appendix.

a. **Phase I.** The oils used in Phase I are formulated for gasoline engines and therefore are different from those used in Phase II. The oil consumption of the gasoline engines was much higher than when MIL-L-2104C oils were used. There was no degradation of the oils as determined by chemical and spectrometric analyses. The engines ran the entire endurance test without an oil change. However, the high oil consumption had the effect of replenishing the oil every 100 hours. No further discussion of Phase I is warranted because the high oil consumption is undesirable.

Table 7. Summary of Oil Consumption - Phase II

| Unit Size | Total Oil (qt) | Consumption Rate - Quarts per 100 Hours | | | | | |
|------------------------------|-------------------|---|-------------------|-------------------|-------------------|--------------------|---------|
| | | 1st 1000 Hours | 2nd 1000 Hours | 3rd 1000 Hours | 4th 1000 Hours | 5th 1000 Hours* | Average |
| Consumption for Oil A | | | | | | | |
| 5-kW | 59.0 | 0.75 | 1.20 | 1.25 | 1.45 | 1.34 | 1.20 |
| 10-kW | 64.8 | 0.88 | 1.20 | 1.42 | 1.65 | 2.27 | 1.41 |
| 15-kW | 44.8 | 0.88 | 1.08 | 0.90 | 1.20 | 0.67 | 0.91 |
| 15-kW | 60.0 | 0.65 | 1.00 | 0.85 | 1.35 | 2.20 | 1.21 |
| 30-kW | 220.5 | 2.90 | 4.60 | 0.47 | 6.50** | 6.60 | 4.79 |
| 60-kW | 204.5 | 5.10 | 4.50 | 0.45 | 3.90 | 4.80 | 4.54 |
| 100-kW | | | | | | | |
| Consumption for Oil B | | | | | | | |
| 5-kW | 35.5 | 0.38 | 1.00 | 0.90 | 0.98 | 1.50 | 0.85 |
| 10-kW | 66.5 | 0.92 | 1.08 | 1.00 | 2.20 | 2.07 | 1.41 |
| 15-kW | 31.5 | 0.45 | 0.95 | 0.60 | 0.85 | 1.00 | 0.73 |
| 30-kW | 97.8 | 0.16 | 0.23 | 1.82 | 2.00 | 2.62 | 2.04 |
| 60-kW | 87.5 | 0.13 | 0.13 | 1.55 | 2.00 | 4.33 | 1.90 |
| 100-kW | 296.0 | 0.64 | 1.06 | 5.88 | 5.70 | 5.00 | 7.05 |

* All but one unit operated less than 1000 hours.

** Unit experienced oil seal leakage problem.

iv. Phase II.

(1) 100-kW Generator Sets.

(a) Chemical Data. Pentane insolubles increased in the Type A oil. The mean values of 0.180 vs 0.146 are an indication of this general trend. The data with respect to the midrange cumulative hours (1500-3000) engine running time also favor Type B oil.

The viscosity of both oils indicated one significant departure from mean values in Engine 1 from 2200- to 3000-cumulative-hour time frame in Type A oil and in Engine 14 from 1500- to 1900-cumulative-hour time frame in Type B oil.

The total acid for Type A oil had three significant increases in the first 1200 hours of testing. The system settled out after this time frame to an overall mean value of 4.4. The total base value decreased to 1; however, an oil change at 5500 hours reversed the trend and brought the system back to average values throughout the remainder of the test period. The total acid and total base values for Type B oil followed a more uniform pattern as indicated by standard deviation data of 0.67 vs. 1.5 and 0.94 vs 1.7. In general, the lower mean values throughout the test period indicates less acid buildup in Type B oil usage.

(b) Spectrographic Data. The Type A oil demonstrated a significant increase in the lead content. This would signify a possible bearing problem with these engines. However, as the cumulative engine time increased beyond 3000 hours, the metal content normalized to initial levels. This pattern was not repeated with oil B and thus would signify a true wear/lubrication relationship at the indicated time frame. The Type B oil demonstrated a moderate increase in the tin analysis. This indicates a heavy wear factor or pitting beyond the lead overlay area in either the main or rod bearings.

The other elements — aluminum, iron, copper, chromium, and silicon — showed no significant increase in wear metal content. However, each engine displayed unusual variations in maximum/minimum data curve configurations, but the significance was masked by the unusual amounts of oil added to each generator.

(2) 60-kW Generator Sets.

(a) Chemical Data. The pentane insolubles in Type A oil were increased significantly over Type B. This pattern is similar to the 100-kW reported earlier in this report; however, engine No. 13 had two oil changes in the 5000-hour test cycle period. This makes comparative analysis difficult; however, a few generalizations follow:

Type A oil demonstrated a more uniform viscosity profile and less total acid buildup in the system; a low TBN value (alkaline reserve) for Type B oil was reflected at 1400 and 3200 hours necessitating oil changes at these intervals.

(b) **Spectrographic Data.** Type B oil indicated a significant increase in the iron wear metal contents; which indicates a general wear problem in cylinders, shafts, rods, and gears but not specifically related to any one specific area. The most significant wear indicator was shown by the high copper content of the oil; copper is normally found in bushings and bearings. This element demonstrated a 4X increase in the mean values, Type B oil (93.1 p/m) compared to Type A oil (21.9 p/m); this signifies a major wear area for this engine/oil combination. Type A oil spectrographic patterns of the tin wear metal were improved (less wear indicated) over Type B oil; however, wide fluctuations of this index for both engines decreased the forecast value of these data. In general, Type A oil appeared to demonstrate less wear than Type B.

(3) 30-kW Generator Sets.

(a) **Chemical Data.** The chemical analyses of the Type A and B oils for these engines are comparatively similar with a slight edge in favor of Type B oil. The pentane insolubles and the total acid mean values were slightly higher in Type A oil. The viscosity increased to approximately 22 cSt from 3800 to 4200 engine hours in Type B oil, but returned to normal, 12 cSt, after the above period. The only explanation for this event is that the oil consumption trend decreased slightly during this period, which increased the viscosity of the remaining oil in the sump.

(b) **Spectrographic Data.** Type A oil demonstrated increases in aluminum, iron, and lead when compared to Type B oil. This indicates an overall wear problem throughout the engine and could be related to a difference in oil lubrication performance.

Specifically, the individual elemental graphs indicate abnormal patterns for engine No. 3 at 2900 hours for aluminum, 1400 hours for iron, and 1800 hours for lead. An identical lead wear metal pattern was repeated for oil Type B but at a decreased level. The other elements — chromium, copper, tin, and silicon — did not display significant differences in wear patterns.

(4) 15-kW Generator Sets.

(a) **Chemical Data.** The mean values for pentane insolubles and total acid were higher in the Type A oil. Also, the pentane insolubles (Appendix) demonstrated overall excessive levels during midrange engine running time (1800 and 2800 hours). Type B oil peaked at the 3900-hour area and displayed a more uniform viscosity curve

(standard deviation) (0.762 cSt vs 1.34 cSt) for Type A oil; also Type A oil demonstrated a major viscosity increase deviation (16 cSt) (2400) followed by a sharp decrease (9 cSt) without any apparent change in oil consumption patterns.

(b) Spectrographic Data. The wear metal concentration for aluminum was slightly higher in Type A oil. The remaining metal indicators were similar, except for lead, which again increased slightly in the Type A oil. Also, Type A engine indicated an abnormal spike in the copper line but returned to average values at 1100 hours. The trend in Type B oil was reversed and no explanation can be found for this result. In general, with the above exceptions, the specific curves for each metal indicator displayed similar patterns. The silicon, lead, iron, tin, and chromium patterns were uniform throughout the test period.

(5) 10-kW Generator Sets.

(a) Chemical Data. The viscosity and total acid for both oils increased with engine running time. Type A oil viscosity values peaked at 33 cSt and Type B oil, at 30 cSt. Type A oil developed a significant amount of acid 6.37 vs 4.54 mean values for Type B oil. More significantly, during the last 1000 hours of running time, the values of A oil were doubled (10 vs 5 for Type B oil). Comparisons can be generalized only since Type B oil/engine system had one oil change at 2600 hours and used more oil (5.5 quarts) than did Type A during the same period.

(b) Spectrographic Data. The wear metal concentration for lead in Type A oil was significantly higher than in Type B oil. The specific wear pattern for each engine/oil was similar with the highest wear indicated near 2000-hour engine running time. The Type B oil demonstrated an abnormal spike at 400 hours but returned to normal values at 500 hours. Except for the above-mentioned peak, Type B oil was consistently lower throughout the test period. The mean value for aluminum was slightly higher in Type A oil; the remaining elements were similar in both systems. The chromium value for Type B oil demonstrated an unusual spike at the end of the test period; while the silicon wear metal indicator became apparent at 1200 hours in Type A oil and 2600 and 4200 hours in Type B oil.

(6) 5-kW Generator Sets.

(a) Chemical Data. The total acid for Type A oil significantly increased to peak values of 10 during the last 1000-hour test cycle. Type B oil demonstrated lower and more uniform values during the total test period. The pentane insolubles also increased significantly during the total test period for Type A oil. Both engine/oil sets displayed high initial results in the first 500 hours of engine running time. The viscosity displayed a generally normal response trend with ranges of 25 cSt for Type A oil and 15 cSt for Type B oil during the last 1000-hour test cycle.

(b) Spectrographic Data. The iron wear metal concentration for Type B oil was higher than for Type A. The wear metal pattern was similar with two abnormal patterns at 1500 and 3500 hours for Type B and 1500 and 4000 for Type A. The mean value for lead was also significantly higher for Type B oil, but the wear patterns were different. The copper wear metal indicator was slightly increased (10 p/m) over Type B oil; with both engines displaying highest wear values during the 2500- to 3000-hour test period. Silicon metal increased wear values through the 4000-hour test period for both engines; the mean values were similar — 14.9 for Type A oil and 16.6 for Type B oil.

c. Data Presentation. Chemical analyses data are summarized in Tables 8 and 9; data for spectrographic analyses are in Tables 8 and 9; data for oil consumption are in Table 7. Chemical analysis for each engine/oil type is located in the Appendix. Spectrographic analysis wear metals for each engine/oil type is located in the Appendix.

9. Engine Teardown Inspections. Inspections were conducted on the engines and lubricants contained in Table 12.

a. Wear Ratings. The inspection wear ratings were made in accordance with CRC Manual N05 except in the case of piston deposits where the CRC "F" system was used. Detailed ratings are attached in Table 11.

b. Analysis of Data. Differences in performance were observed between the two test lubricants. As can be seen from Table 10, oil B offered better control of piston deposits than did oil A. Although piston deposits were considered acceptable for the majority of the engines, they did present a problem in the 5- and 10-kW units. Here, the high level of deposits caused excessive loss of ring side clearance which resulted in numerous instances of stuck or sluggish compression rings. Also, it is believed these deposits contributed to the severe distress observed in the No. 4 cylinder of EZ00052 (10-kW unit, STA No. 5). Other differences were observed in the area of intake valve and combustion chamber deposits: engines operated on oil A had lower levels of intake valve deposits while those operated on oil B consistently had less combustion chamber buildup. With the exception of the aforementioned piston deposits exhibited by the 5- and 10-kW units, the observed deposition levels were considered satisfactory.

Table 11 summarizes inspection findings other than the previously discussed deposit ratings. With a few exceptions, conditions of the engines were considered acceptable; however, it was noted that lubricant B allowed a slightly higher level of distress/wear than did oil A. Exceptions to satisfactory performance are as follows:

(1) 5-kW Units. Both units experienced excessive wear to govenor assemblies. Based on previous testing with MIL-L-2104C lubricants, the wear problem was attributed to governor design and not considered related to the performance of the oils under test.

Table 8. Summary of New and Used Oil Analyses – Phase II (Oil A)

| Property | New Oil | Average Value for Generator – Used Oil | | | | | Used Oil 100-kW |
|------------------------------------|------------|--|-------|-------|-------|-------|--------------------|
| | | 5-kW | 10-kW | 15-kW | 30-kW | 60-kW | |
| Viscosity (cSt) @ 210° F | 10.32 | 16.21 | 17.74 | 11.45 | 11.11 | 10.64 | 10.33 |
| @ 210° F | 72.1 | 152.6 | 184.5 | 92.6 | 87.9 | 88.1 | 80.9 |
| TAN | 2.1 | 6.0 | 6.4 | 5.1 | 5.0 | 5.1 | 4.4 |
| TBN | 3.7 | 4.0 | 3.3 | 3.1 | 2.4 | 2.8 | 3.7 |
| Pentane Insolubles (%) | 0.0 | 0.22 | 0.17 | 0.21 | 0.19 | 0.20 | 0.18 |
| Elemental (Wear/Contaminant) (p/m) | | | | | | | |
| A1 | 13 | 31 | 28 | 23 | 33 | 20 | 17 |
| Fe | 0 | 373 | 383 | 190 | 344 | 111 | 115 |
| Cr | 0 | 18 | 15 | 13 | 15 | 7 | 4 |
| Cu | 0 | 24 | 32 | 15 | 12 | 22 | 62 |
| Sn | 8 | 24 | 25 | 23 | 23 | 16 | 17 |
| Pb | 0 | 1.6 | 216 | 125 | 144 | 52 | 111 |
| Si | 4 | 15 | 14 | 11 | 14 | 9 | 8 |

Table 9. Summary of New and Used Oil Analyses - Phase II (Oil B)

| Property | New Oil | Average Value for Generator - Used Oil | | | | |
|------------------------------------|------------|--|-------|-------|-------|-------|
| | | 5-kW | 10-kW | 15-kW | 30-kW | 60-kW |
| Viscosity (cSt) @ 210° F | 10.58 | 12.96 | 16.27 | 10.46 | 10.30 | 10.26 |
| @ 210° F | 61.3 | 93.7 | 130.3 | 67.3 | 67.7 | 67.9 |
| TAN | 2.1 | 3.8 | 4.5 | 4.7 | 4.3 | 5.2 |
| TBN | 3.5 | 3.3 | 2.5 | 2.2 | 2.6 | 2.3 |
| Pentane Insolubles (%) | 0.0 | 0.12 | 0.16 | 0.14 | 0.15 | 0.14 |
| Elemental (Wear/Contaminant) (p/m) | 10 | 22 | 20 | 15 | 20 | 15 |
| Al | 0 | 450 | 363 | 200 | 247 | 218 |
| Fe | 0 | 19 | 14 | 13 | 14 | 9 |
| Cr | 0 | 14 | 13 | 11 | 13 | 93 |
| Cu | 9 | 23 | 25 | 21 | 21 | 22 |
| Sn | 0 | 221 | 157 | 96 | 77 | 46 |
| Pb | 4 | 17 | 12 | 11 | 9 | 12 |
| Si | 4 | 17 | 12 | 11 | 9 | 7 |

Table 10. Summary of Engine Deposit Ratings

| Units | STA No. | Oil | Piston Deposits ^a | | | Valve Deposits ^c | | Combustion Chamber ^c |
|--------|---------|-----|------------------------------|------|---------------------|-----------------------------|---------|---------------------------------|
| | | | TGF | WTD | Sludge ^b | Intake | Exhaust | |
| 5-kW | 6 | A | 98 | 3526 | 9.4 | 3.5 | 1.0 | 1.5 |
| 5-kW | 9 | B | 90 | 1059 | 9.5 | 4.0 | 1.0 | 2.0 |
| 10-kW | 5 | A | 100 | 3914 | 9.4 | 4.0 | 1.0 | 3.4 |
| 10-kW | 10 | B | 92 | 2833 | 9.2 | 4.5 | 1.0 | 2.8 |
| 15-kW | 4 | A | 64 | 1116 | NR | 1.5 | 1.0 | 3.9 |
| 15-kW | 11 | B | 48 | 426 | NR | 3.7 | 1.0 | 2.0 |
| 30-kW | 3 | A | 66 | 1093 | NR | 1.7 | 1.0 | 3.0 |
| 30-kW | 12 | B | 61 | 598 | NR | 3.5 | 1.0 | 2.0 |
| 60-kW | 2 | A | 85 | 1989 | 9.1 | 3.0 | 1.0 | 1.2 |
| 60-kW | 13 | B | 93 | 1312 | 9.3 | 4.0 | 1.0 | 1.0 |
| 100-kW | 1 | A | 51 | 419 | 9.7 | 3.3 | 1.0 | 1.1 |
| 100-kW | 14 | B | 29 | 199 | 9.7 | 3.8 | 1.0 | 1.0 |

^a TGF = Top Groove Filling, %; WTD = Weighted Total Demerit

^b 10 = Clean, NR = Not rated

^c Deposits were assigned the following demerits: Heavy = 10, Medium = 5, Light = 2, and Very Light = 1. The demerits were weighted using the percent coverage by a deposit level and then averaged for the engine.

Table 11. Summary of Engine Condition

| Unit | Oil A Lubricated Engines | | Oil B Lubricated Engines |
|--|---|---|---|
| | Piston and Cylinders | | |
| 5kW | No unusual conditions. | | No unusual conditions. |
| 10kW | Severe distress No. 4 cylinder and piston (scored; scuffed). | | No unusual condition. |
| 15kW | No unusual condition. | | No unusual condition. |
| 30kW | Deep scratch No. 2 cylinder due to broken ring. | | No unusual condition. |
| 60kW | Light wiping on pin bushing (con. rod). Wear in Nos. 3, 4, and 6 cylinders. | | Pin bushing wear (con. rod). Wear in Nos. 3, 4, and 6 cylinders. |
| 100kW | No unusual condition. | | No unusual condition. |
| Rings | 5kW | Two stuck. | Oil ring spring worn. |
| | 10kW | Two stuck; two sluggish; face distress all rings No. 4 piston. | Three stuck. |
| 15kW | No unusual condition. | | All No. 1 compression rings showed signs of blowby. |
| 30kW | All oil rings stuck. All No. 1 rings showed signs of blowby. No. 1 ring of piston 2 was broken. | | Five oil rings stuck. All compression rings showed signs of blowby. No. 1 rings of pistons 3 and 5 were broken. |
| 60kW | Some wear on oil ring spring. | | No unusual condition. |
| 100kW | No unusual condition. | | No unusual condition. |
| Rockers (R), Valves (V), and Tappets (\hat{T}) | 5kW | R - no unusual condition. V - slight wear on tip caps. | R - no unusual condition. V - light wear on tip caps, some guide wear, face distress (intake). |
| | 10kW | R - no unusual condition. V - slight on tips and tip caps, face distress (intake). | R - no unusual condition. V - wear on tips and tip caps; one intake showed face distress. |

Table i1. Summary of Engine Condition (Cont'd)

| Unit | Oil A Lubricated Engines | | | Oil B Lubricated Engines | | |
|----------|---|--|---------------------------|---|--|---------------------------------|
| 15-kW | R - no unusual condition. | V - no unusual condition. | T - light scuffing. | R - some indication of wear. | V - medium-to-heavy face wear. | T - light scuffing to scuffing. |
| 30-kW | R - no unusual condition. | V - faces lightly pitted. | T - no unusual condition. | R - light-to-medium wear. | V - medium-to-heavy face wear. | T - no unusual condition. |
| 60-kW | R - wear and scuffing of pads and bushings; shaft showed some scuffing. | V - exhaust tips scuffed, faces pitted, and stem wear. | | R - wear and scuffing of pads, bushings, and shaft. | V - exhaust tips scuffed, faces pitted, and stem wear. | |
| 100-kW | R - slight pad wear; some bushing wear. | V - one face showed channeling; some pitting on two faces. | T - no unusual condition. | R - some slight wear of two pads. | V - two exhaust faces showed channeling. | T - no unusual condition. |
| Bearings | 5-kW | Slight wiping of rod brgs. | | Heavy wiping/wear of rod brgs. | | |
| | 10-kW | Slight wiping of rod brgs. | | Heavy wiping/wear of rod brgs. | | |
| | 15-kW | No unusual condition. | | Light wear pattern of main brgs. | | |
| | 30-kW | No unusual condition. | | Wear of rod brgs. | | |
| | 60-kW | Light pitting of rod brgs. | | One rod brg pitted. | | |
| | 100-kW | Heavy wiping of rod brgs. | | Medium-to-heavy wiping and light pitting of rod brgs. | | |

Table 12. Engines and Lubricants

| Unit | Unit SN | Station No. | Oil | Test Hours |
|--------|---------|-------------|-----|------------|
| 5-kW | EZ00297 | 6 | A | 4906 |
| 5-kW | EZ00937 | 9 | B | 4212 |
| 10-kW | EZ00052 | 5 | A | 4603 |
| 10-kW | EZ00053 | 10 | B | 4707 |
| 15-kW | RZ20030 | 4 | A | 4801 |
| 15-kW | RZ21277 | 11 | B | 4300 |
| 30-kW | RZ51233 | 3 | A | 5003 |
| 30-kW | RZ01245 | 12 | B | 4806 |
| 60-kW | FZ01243 | 2 | A | 4504 |
| 60-kW | FZ01254 | 13 | B | 4606 |
| 100-kW | UZ00709 | 1 | A | 4500 |
| 100-kW | UZ00697 | 14 | B | 4211 |

(2) **10-kW Units.** Both units experienced wear to govenor assemblies. Since these units are identical to those used in the 5kW sets, the previous comments are applicable. Also, unit EZ00052 had severe piston and bore distress of the No. 4 cylinder assembly. This condition was considered related to lubrication as covered (see paragraph b) under the discussion of engine deposits.

(3) **15-kW Units.** None.

(4) **30-kW Units.** None.

(5) **60-kW Units.** Both units experienced excessive wear and distress of the rocker arm shaft, rocker arms, valves, and valve guides. Since similar distress was observed in previous tests, the problem was not considered a function of test lubricant performance.

(6) 100-kW Units. After 2500 hours of operation, both engines required replacement of the rocker arm shafts because of excessive wear. The wear problem was considered to be design related (i.e., size of the lubricant passage) and not associated with performance of the test oils. The shaft has been redesigned by the manufacturer. It should be noted that the problem, wear and pitting of connecting rod bearings, was observed. This problem may have been related to oil performance or the duration of lubricant usage.

10. Economic Analysis. A detailed economic analysis is available in the engineering division.

A list of worldwide assets of each generator set size as obtained from the Worldwide Inventory Stratification Report as of December 1979 follows:

| <u>Generator Size</u> | <u>No. of Sets</u> |
|-----------------------|--------------------|
| 5-kW | 1,082 |
| 10-kW | 3,204 |
| 15-kW | 4,566 |
| 30-kW | 8,723 |
| 60-kW | 8,835 |
| 100-kW | 4,150 |
| Total | 30,560 |

Figure 1 indicates the percentage cost reduction of synthetic vs conventional oils by generator set size. Figure 2 illustrates the annual percentage synthetic oil cost vs conventional oil by oil change interval. Figure 3 compares the cost of synthetic oil and conventional oil by oil change interval. Figure 4 compares the annual cost by generator set size. Figure 5 compares the oil consumption for 100 hours per set. The results in Figures 1 through 5 indicate that the longer the change interval, the greater is the potential cost savings. Since the average usage per year is 1000 hours, this interval is the most logical since oil should be changed at least once a year. The 1000-hour interval yields a cost savings over current intervals approaching \$1 million annually. The cost of conventional oil has been increasing at a greater rate than synthetic oils. In the near future the annual savings could be several million dollars per year. The economic study did not take into account the possible savings related to logistics.

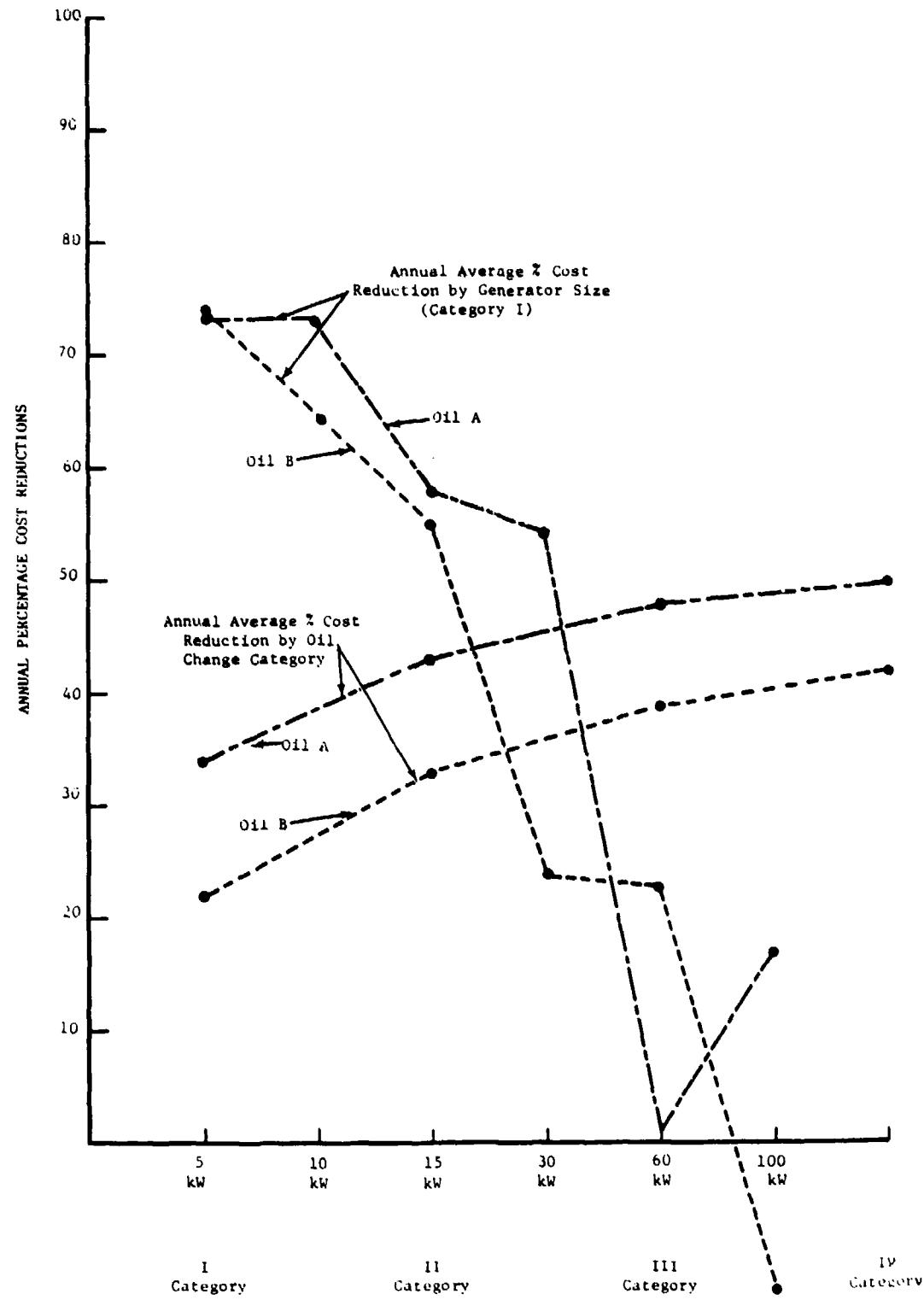


Figure 1. Percent cost reduction - synthetic vs petroleum oil.

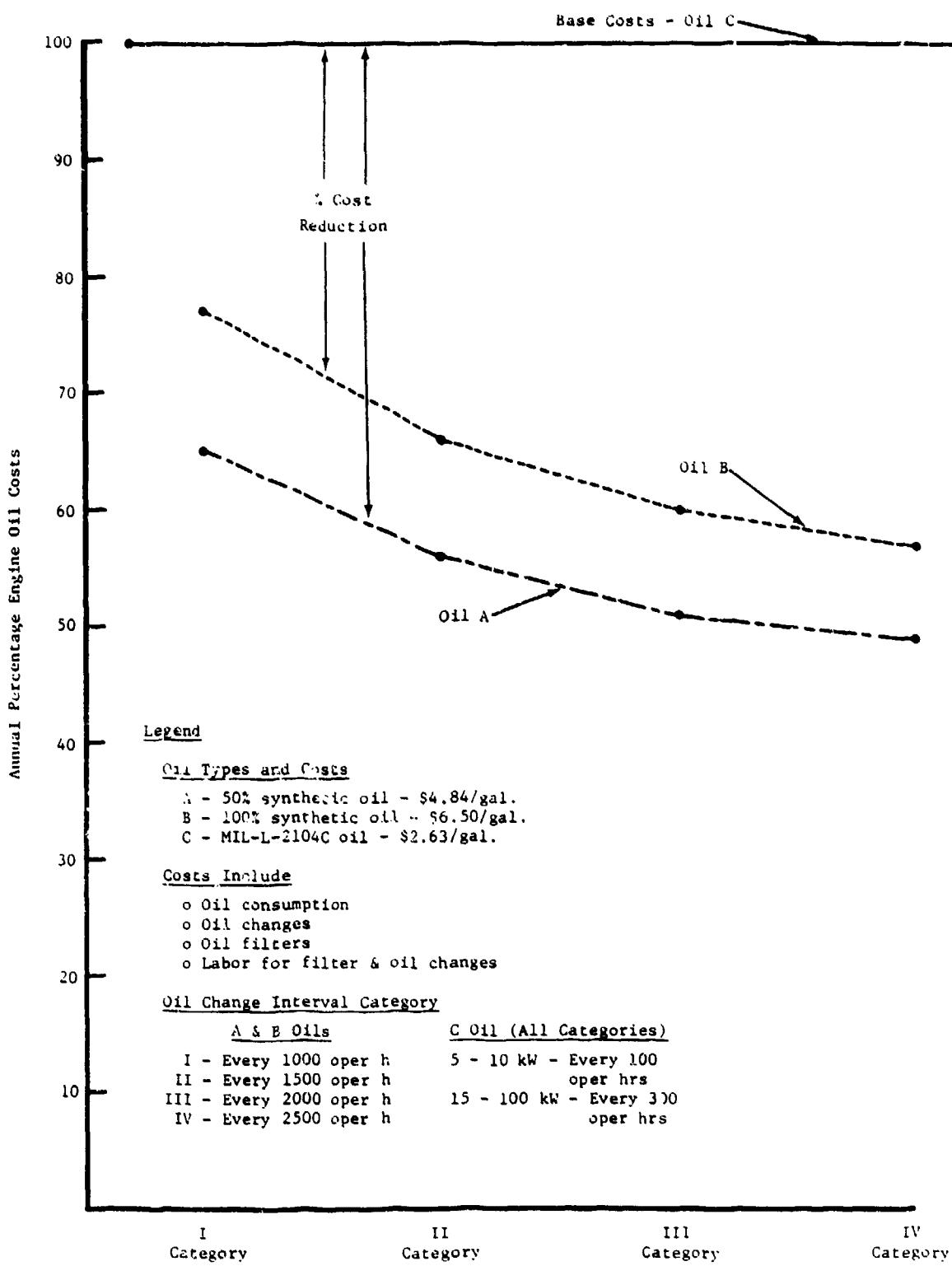


Figure 2. Synthetic oil cost vs base cost MIL-L-2104C

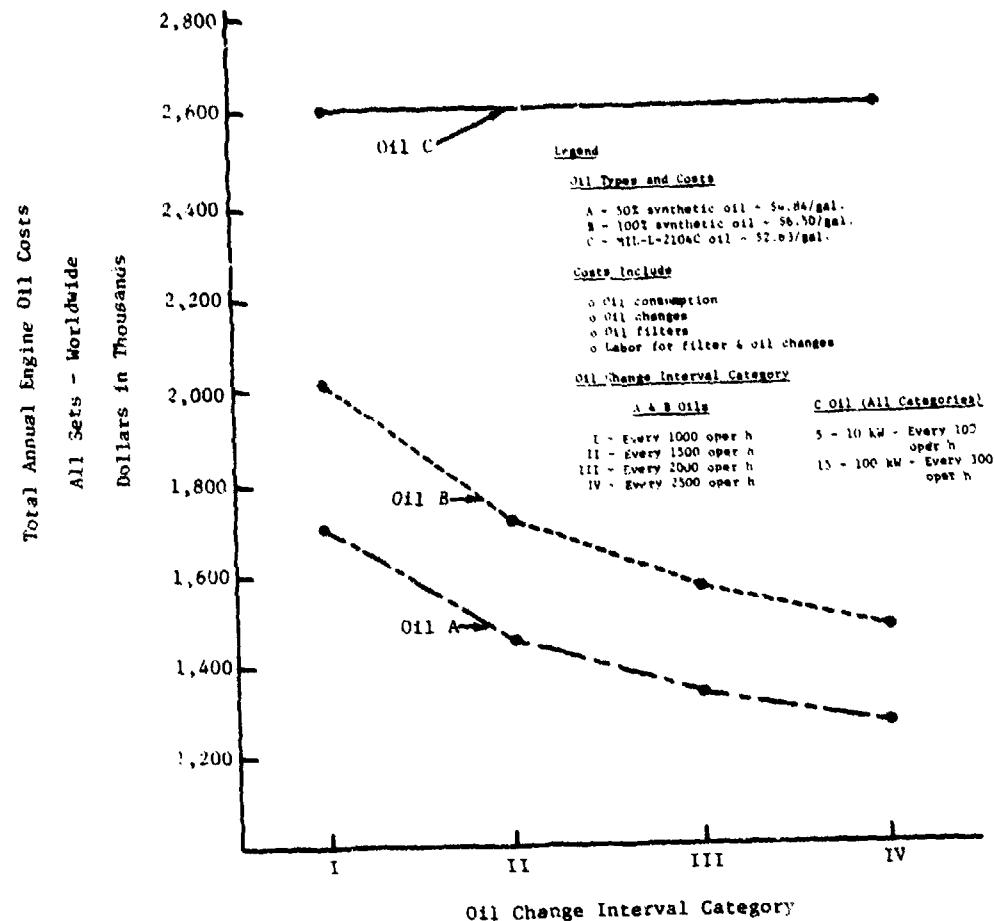


Figure 3. Dollars vs oil change interval.

Total Annual Engine Oil Costs
 All Sets - Worldwide
 Category I Oil Change Interval

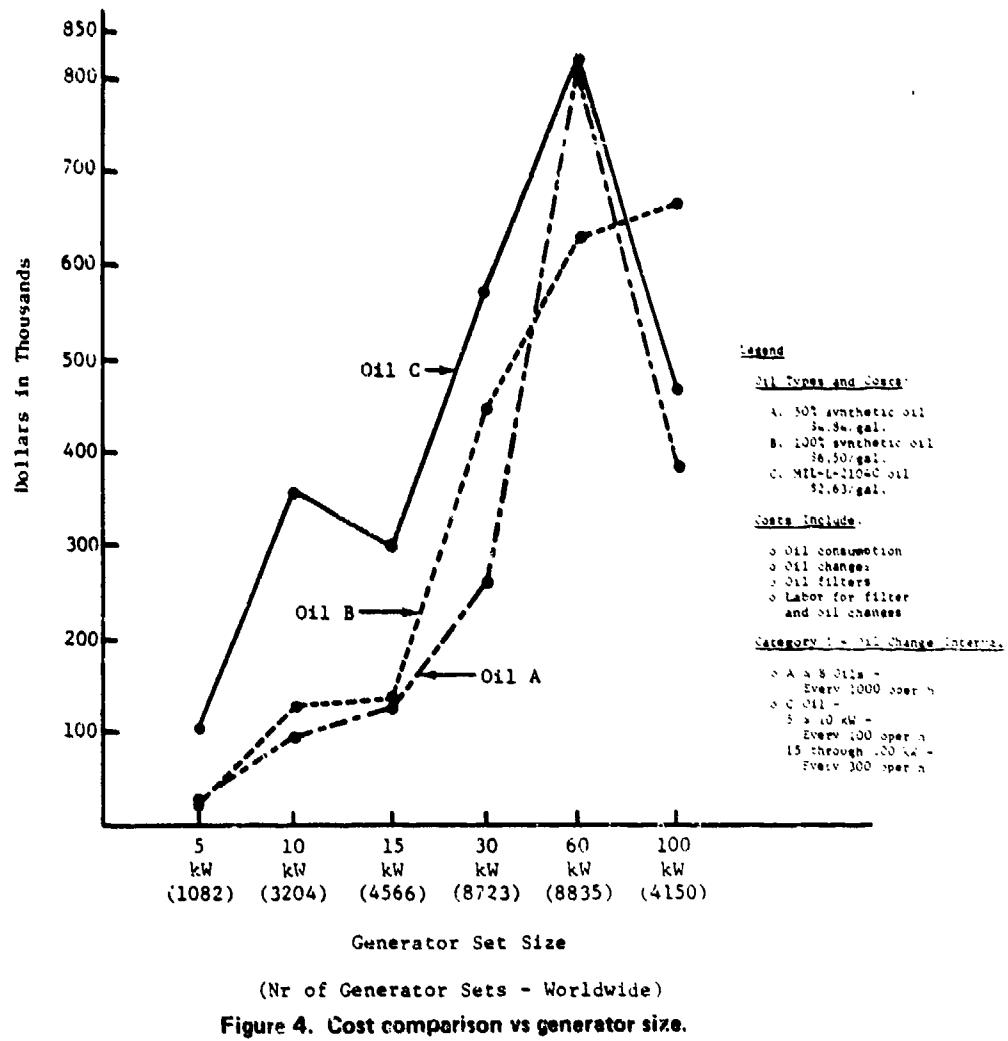


Figure 4. Cost comparison vs generator size.

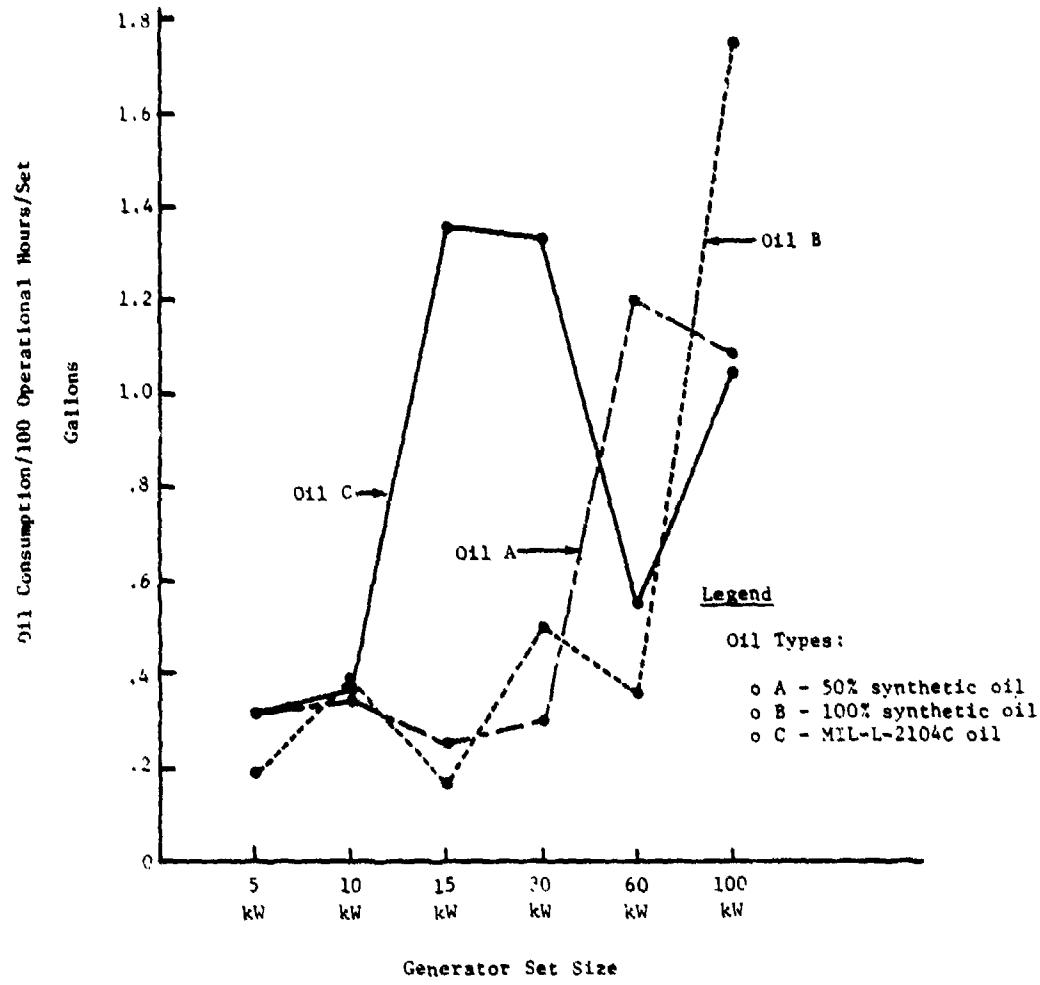


Figure 5. Oil consumption vs generator size.

IV. CONCLUSIONS

11. Conclusions. The following conclusions were made:

- a. There were no failures attributed to use of synthetic crankcase oil.
- b. The present 32° F ambient temperature wherein oil change is required for cold starting can be lowered to 0 to 10° F using synthetic oils of the type tested.
- c. The oil consumption on the small bore gasoline engines is much higher when synthetic oil is used.
- d. It is not economical currently to use synthetic oil in the small bore gasoline engines.
- e. The chemical and spectrometric analysis indicated that the oil performed satisfactory and the the present oil change interval (100 hours, 5- and 10-kW; 300 hours, 15- to 100-kW) for diesels can be extended safely for normal service conditions through use of synthetic oil.
- f. Diesel generator sets ranging in size from 5-kW through 100-kW can operate satisfactorily using synthetic oil with a 1000-hour/1-year change interval without engine performance, reliability, or total life cycle being affected adversely.
- g. When test oil A is used, a 1000-hour/1-year oil-change interval offers the maximum economic benefit and cost-saving compromise to the Military while maintaining a minimum risk of engine malfunctions or failures attributable to extended lubricating-oil change intervals.

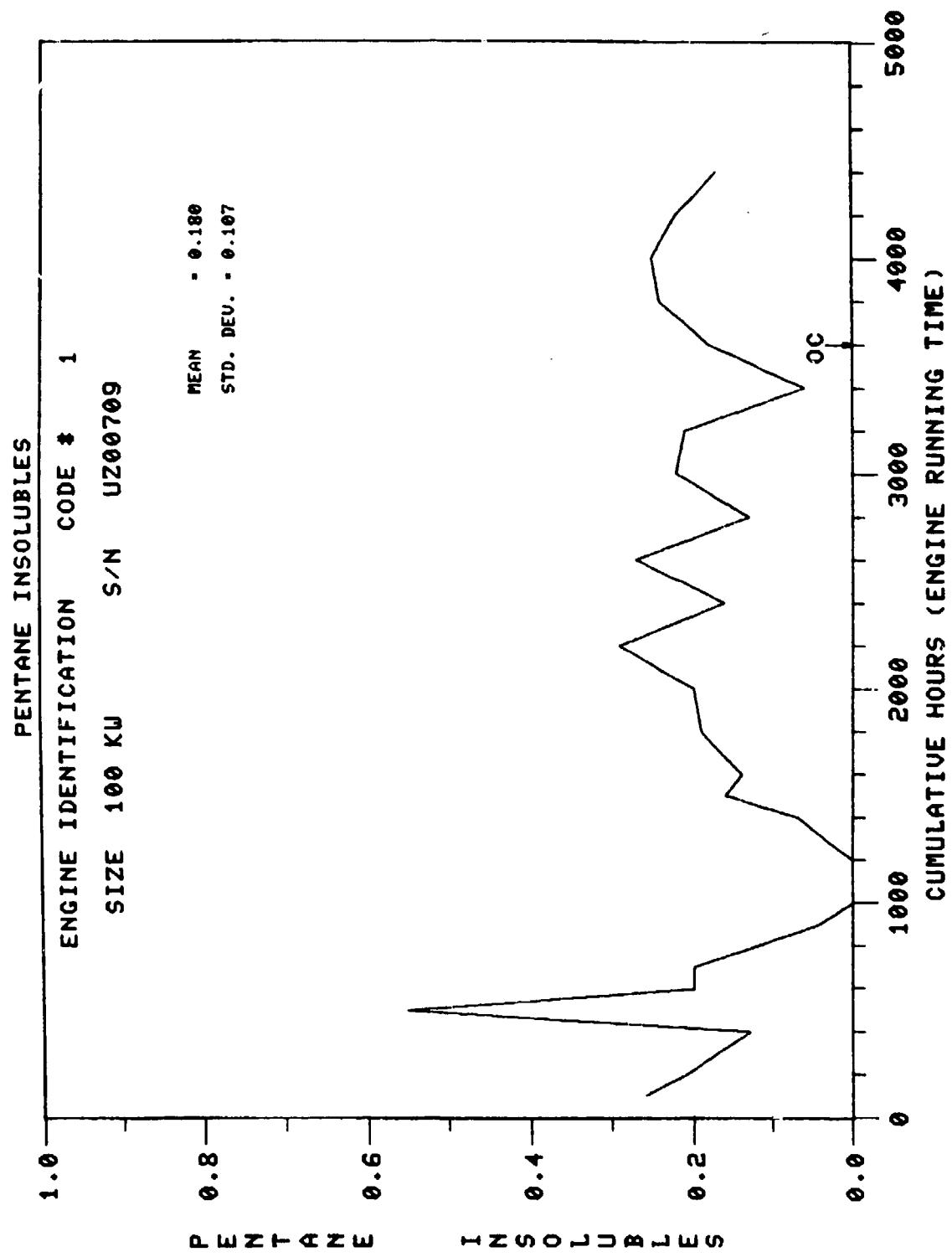
APPENDIX

OIL ANALYSES TEST DATA

LEGEND

ENGINE IDENTIFICATION CODES

| Code | Engine | Generator Set Size (kW) | Oil | Page |
|------|----------------|----------------------------|-----|---------|
| 1 | Caterpillar | 100 | A | 133-144 |
| 2 | Allis Chalmers | 60 | A | 133-144 |
| 3 | White | 30 | A | 133-144 |
| 4 | White | 15 | A | 133-144 |
| 5 | Onan | 10 | A | 133-144 |
| 6 | Onan | 5 | A | 133-144 |
| 9 | Onan | 5 | B | 133-144 |
| 10 | Onan | 10 | B | 133-144 |
| 11 | White | 15 | B | 133-144 |
| 12 | White | 30 | B | 133-144 |
| 13 | Allis Chalmers | 60 | B | 133-144 |
| 14 | Caterpillar | 100 | B | 133-144 |



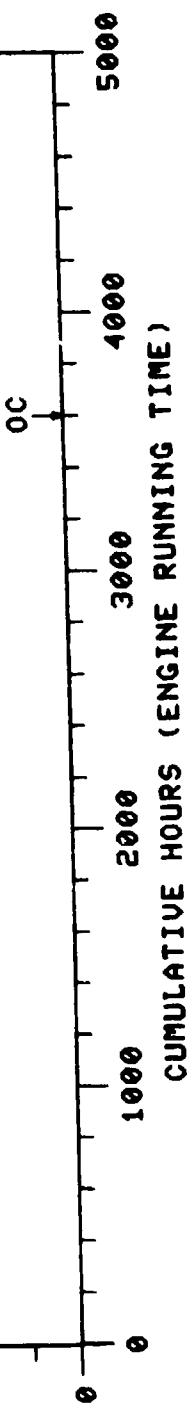
VISCOSITY AT 210 DEGREES F.

ENGINE IDENTIFICATION CODE # 1
SIZE 100 KU S/N U200709

MEAN = 10.333
STD. DEV. = 0.915

V I S C O S I T Y I N C S

15 10

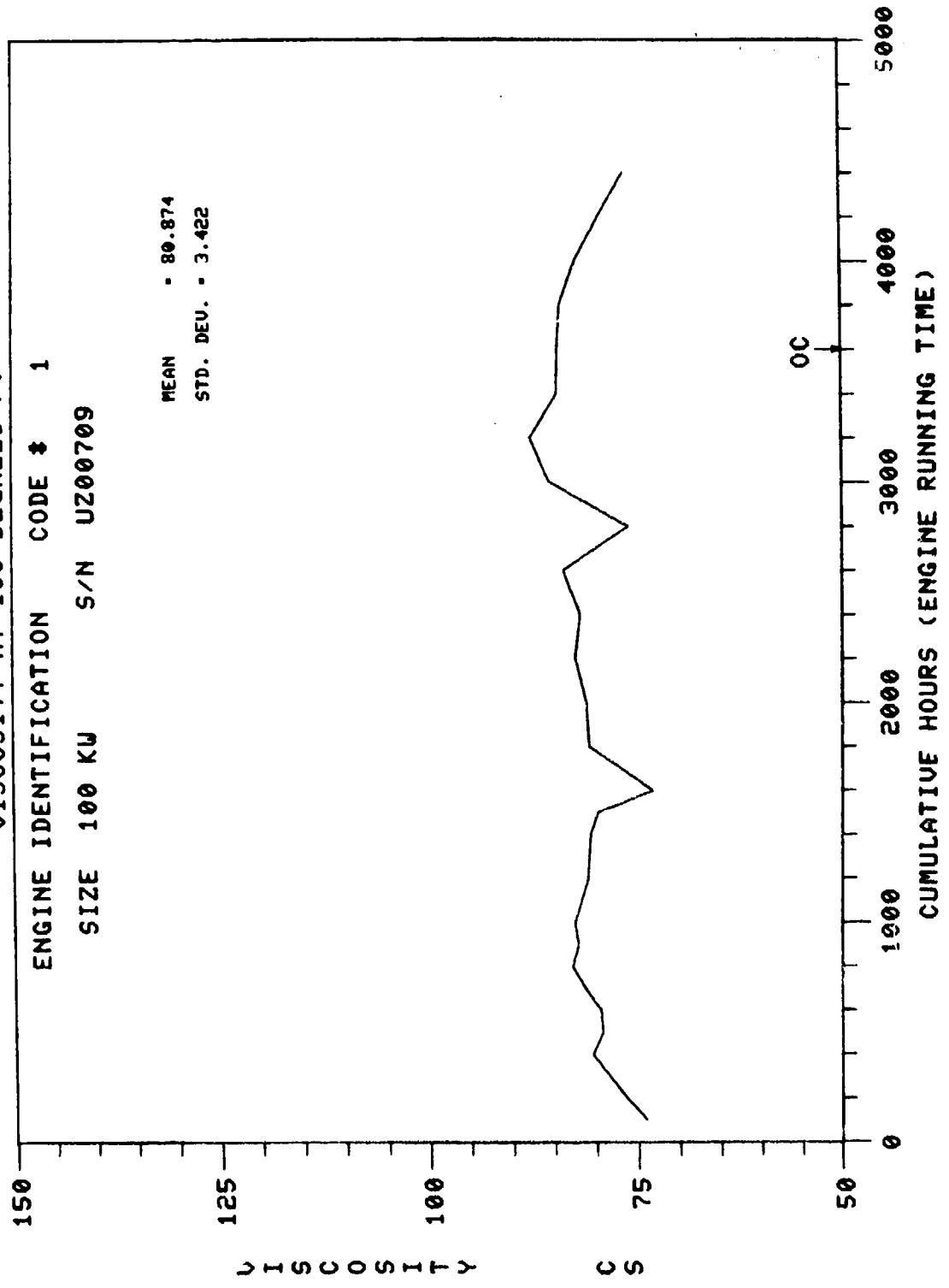


VISCOSITY AT 100 DEGREES F.

ENGINE IDENTIFICATION CODE # 1

SIZE 100 KU S/N UZ00709

MEAN = 89.874
STD. DEV. = 3.422



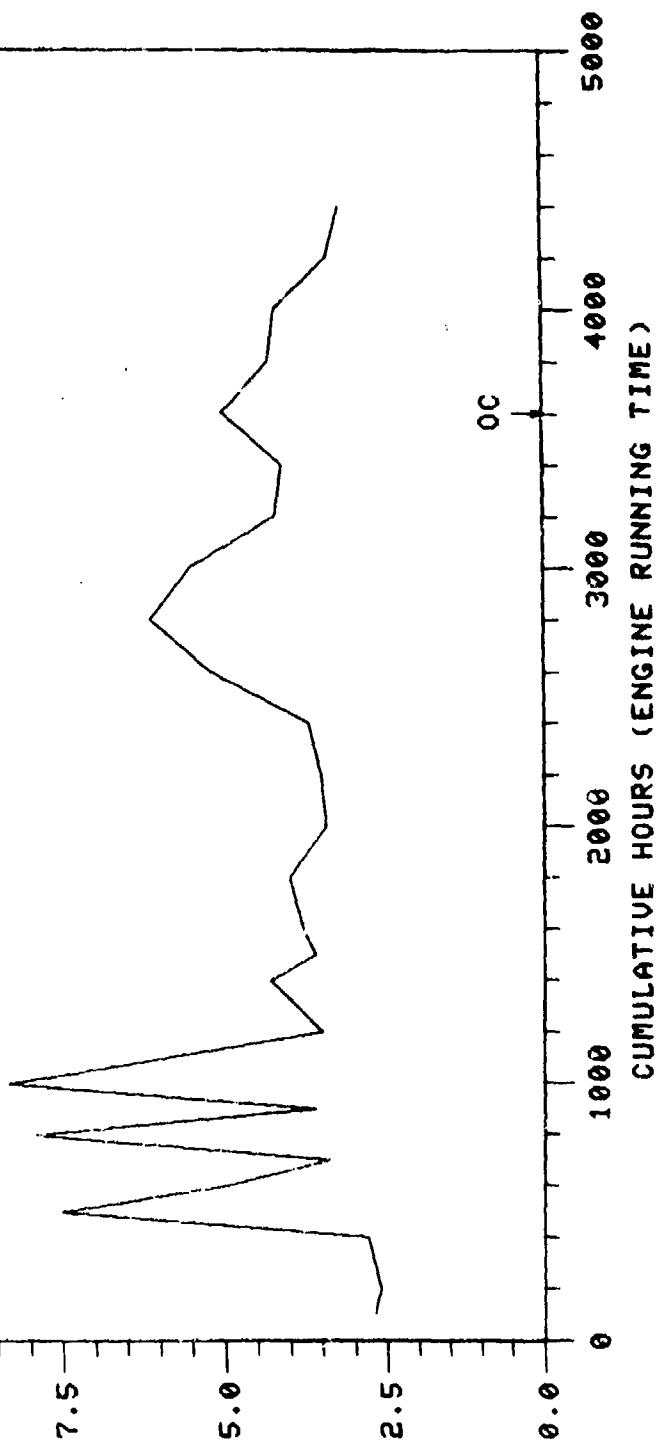
TOTAL ACID IN USED OIL

ENGINE IDENTIFICATION CODE # 1

SIZE 100 KU S/N UZ00709

MEAN = 4.401
STD. DEV. = 1.515

T 10.0
A 7.5
L 5.0
C 2.5
I N 0
D .



TOTAL BASE IN USED OIL

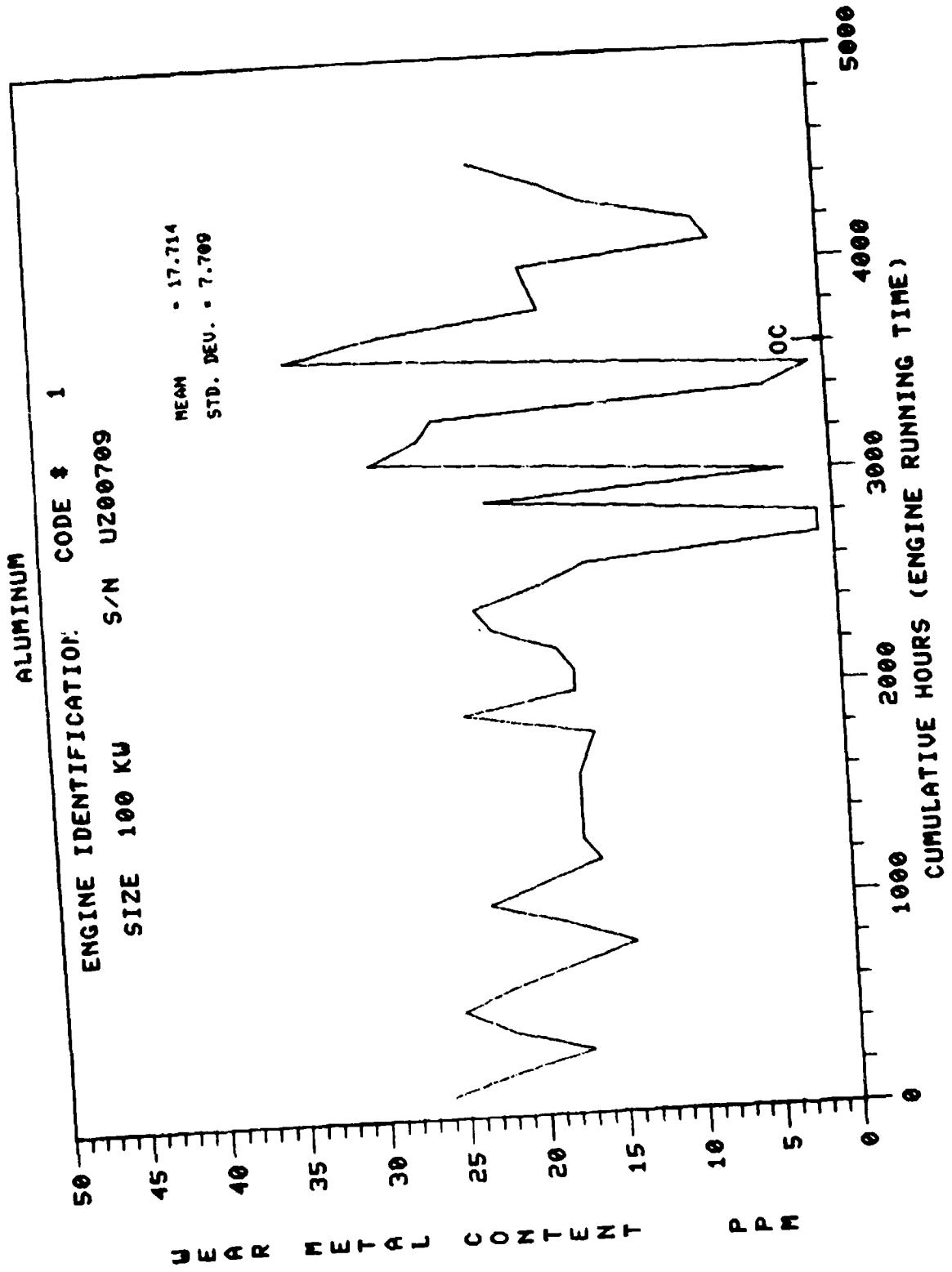
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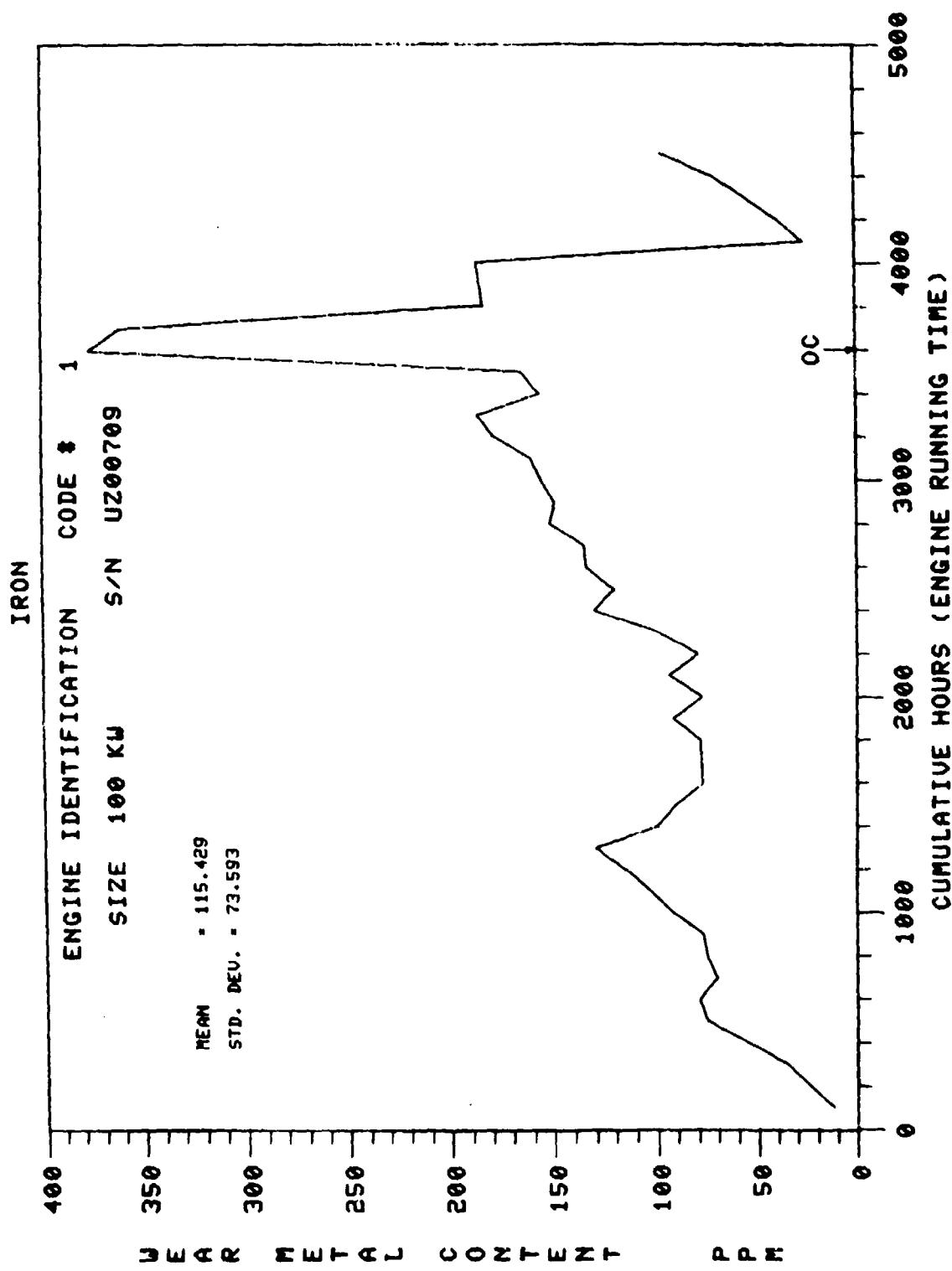
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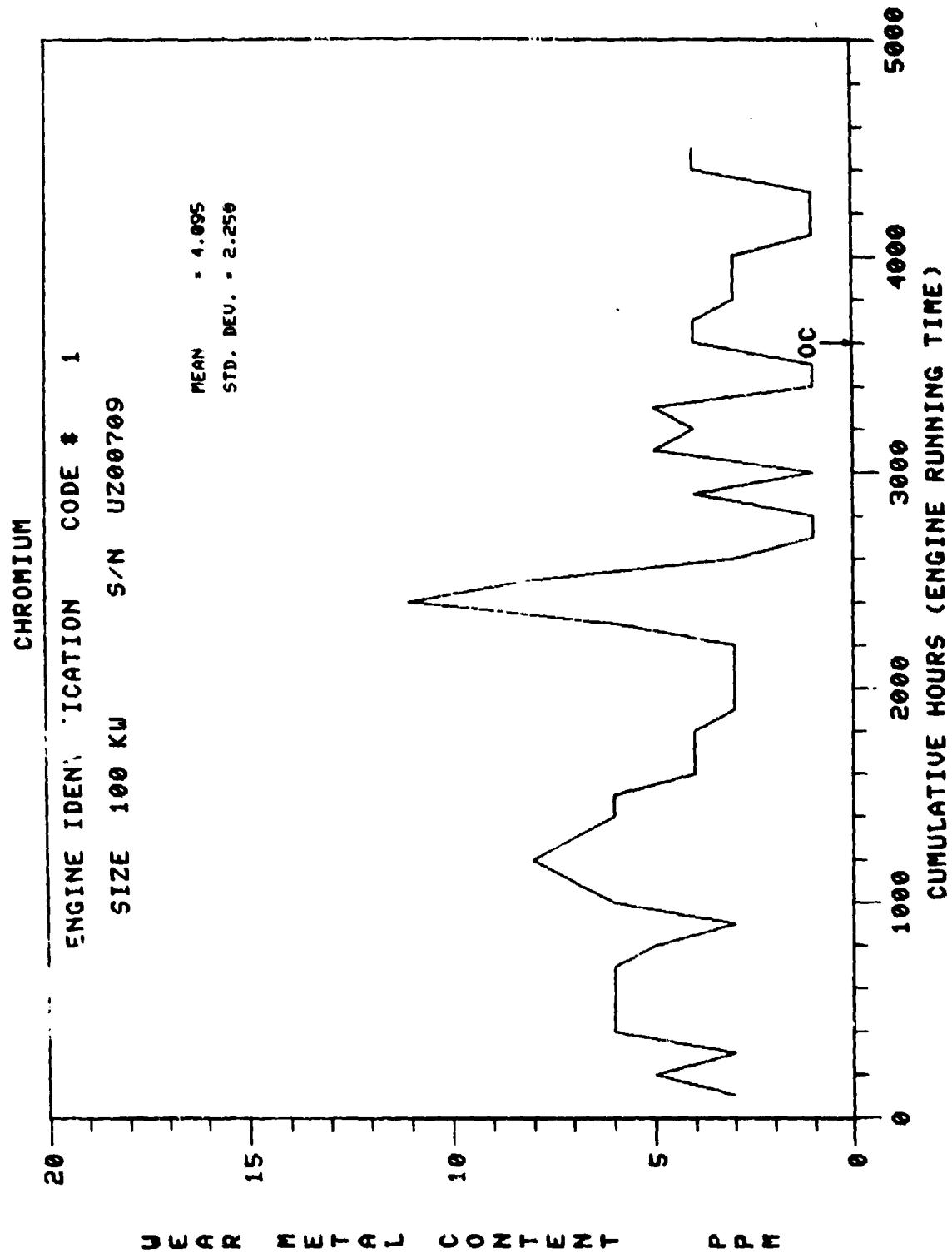
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STD. DEV. = 1.650

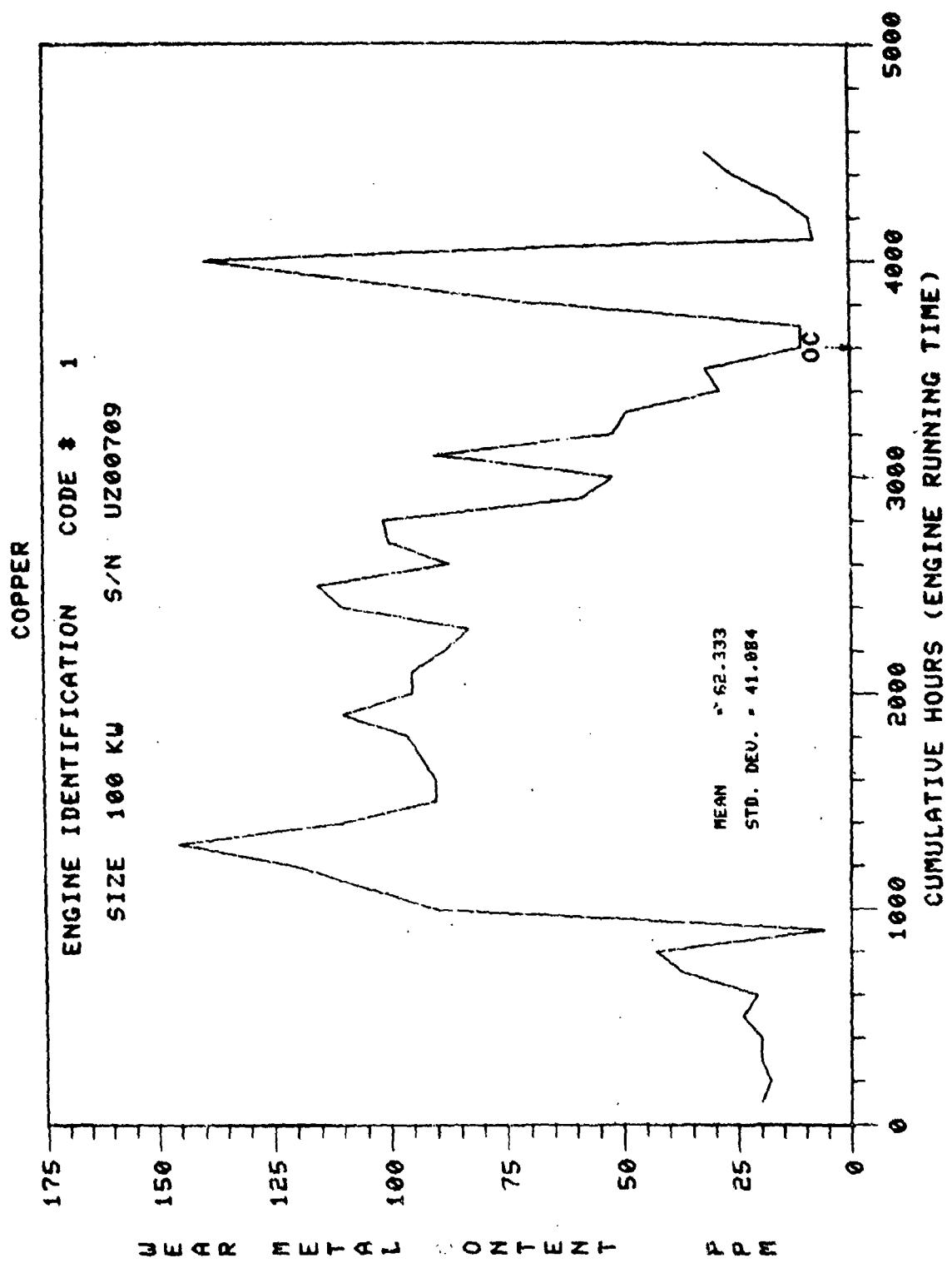
TOTAL BASE NO.

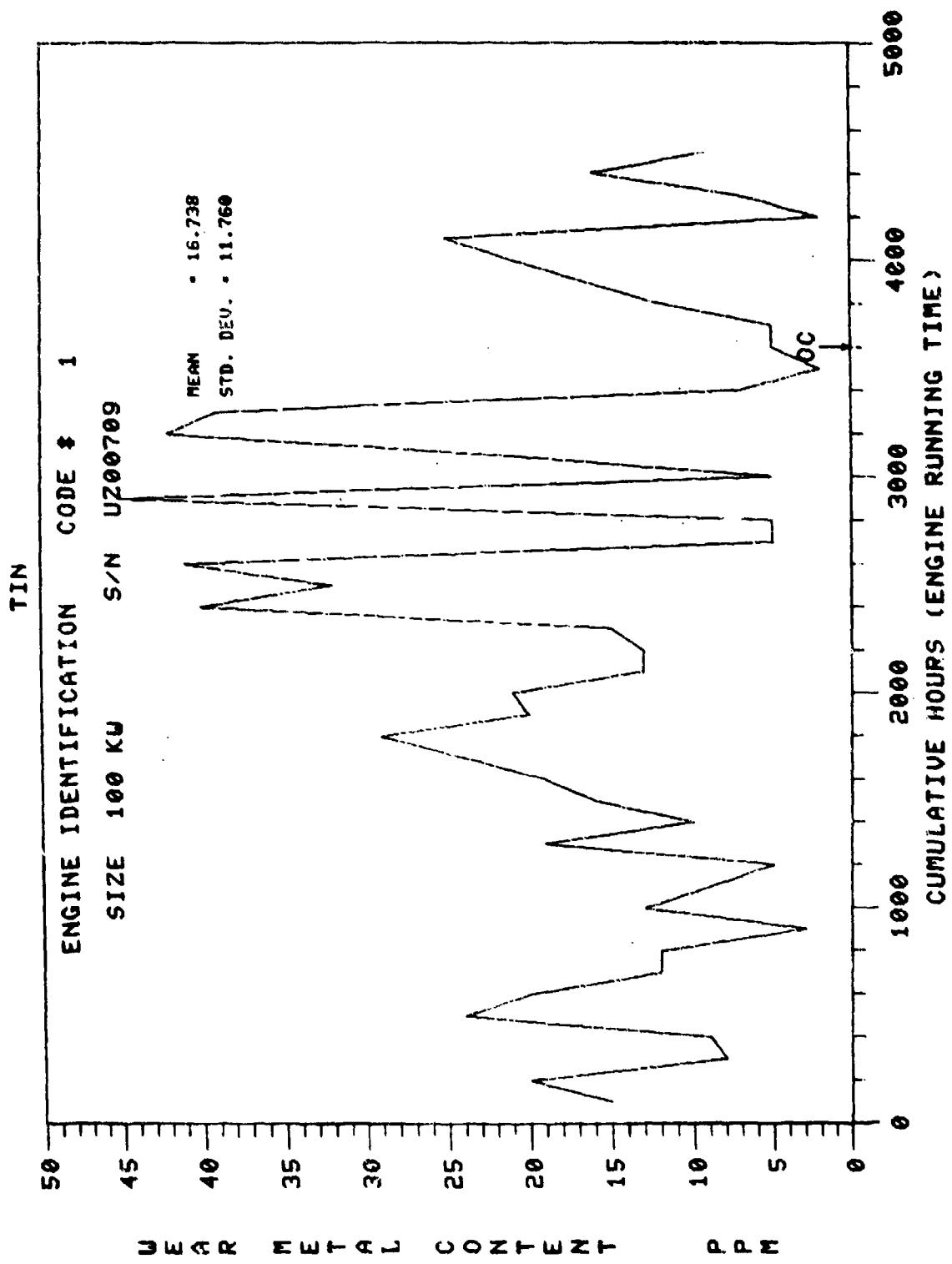


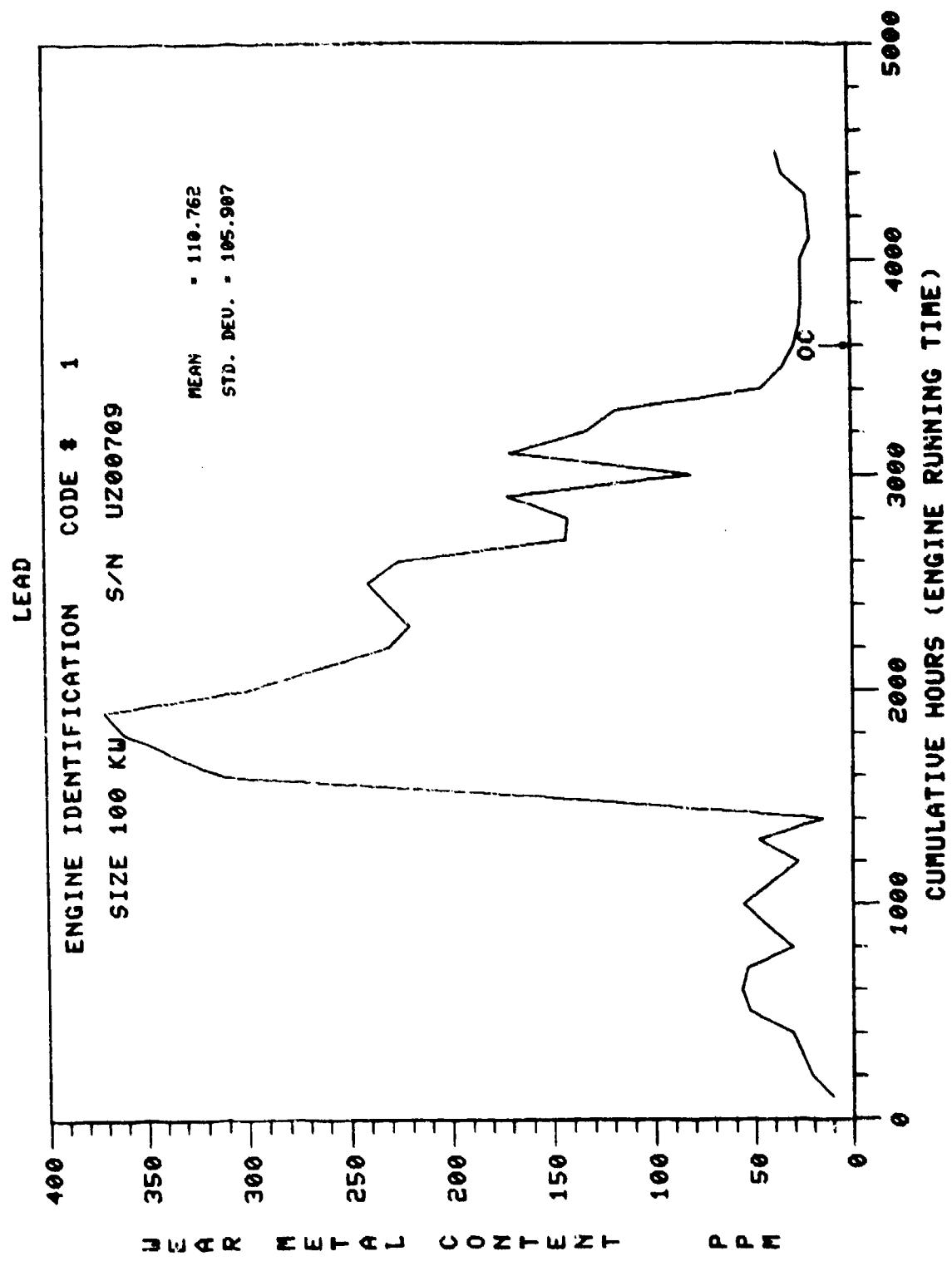


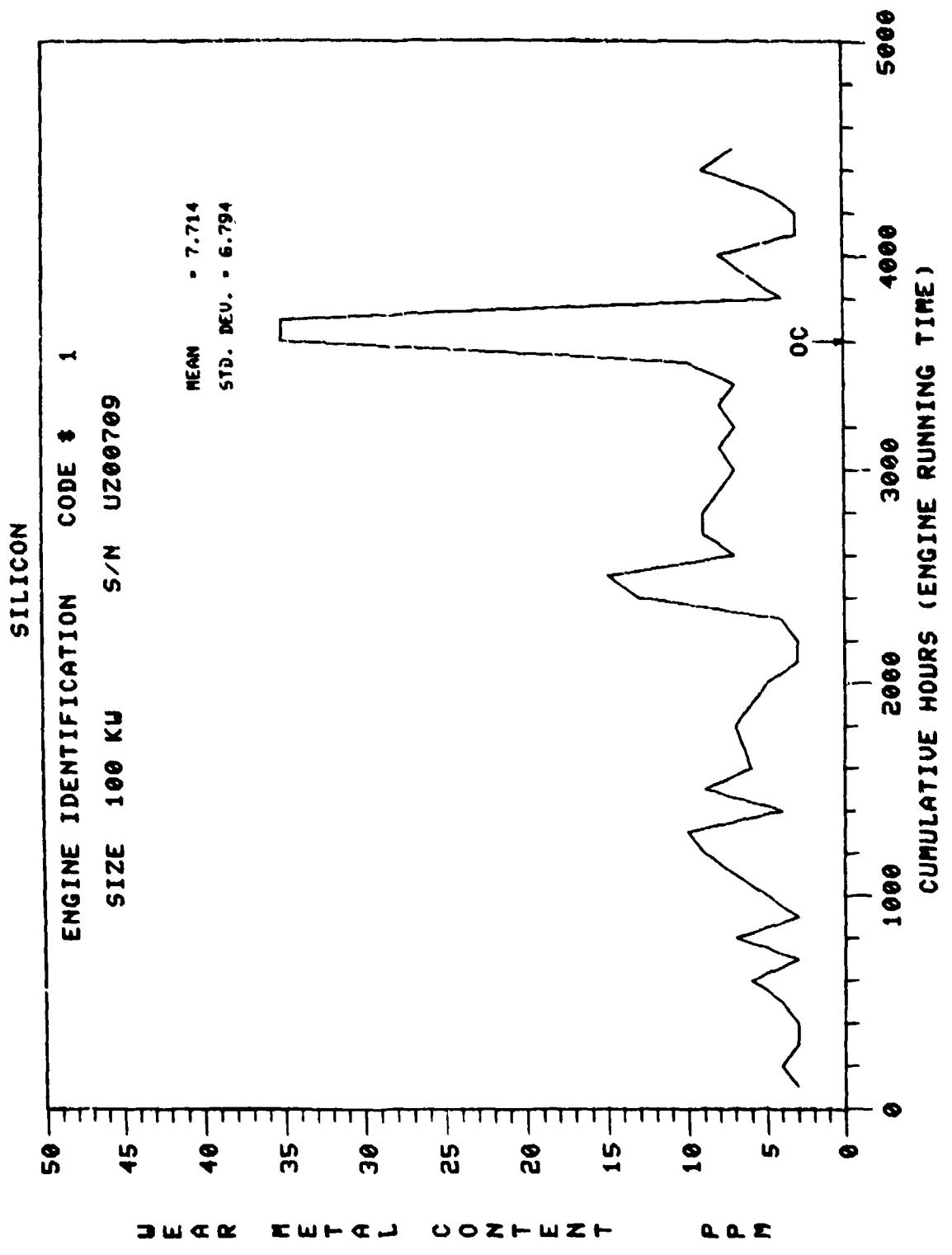


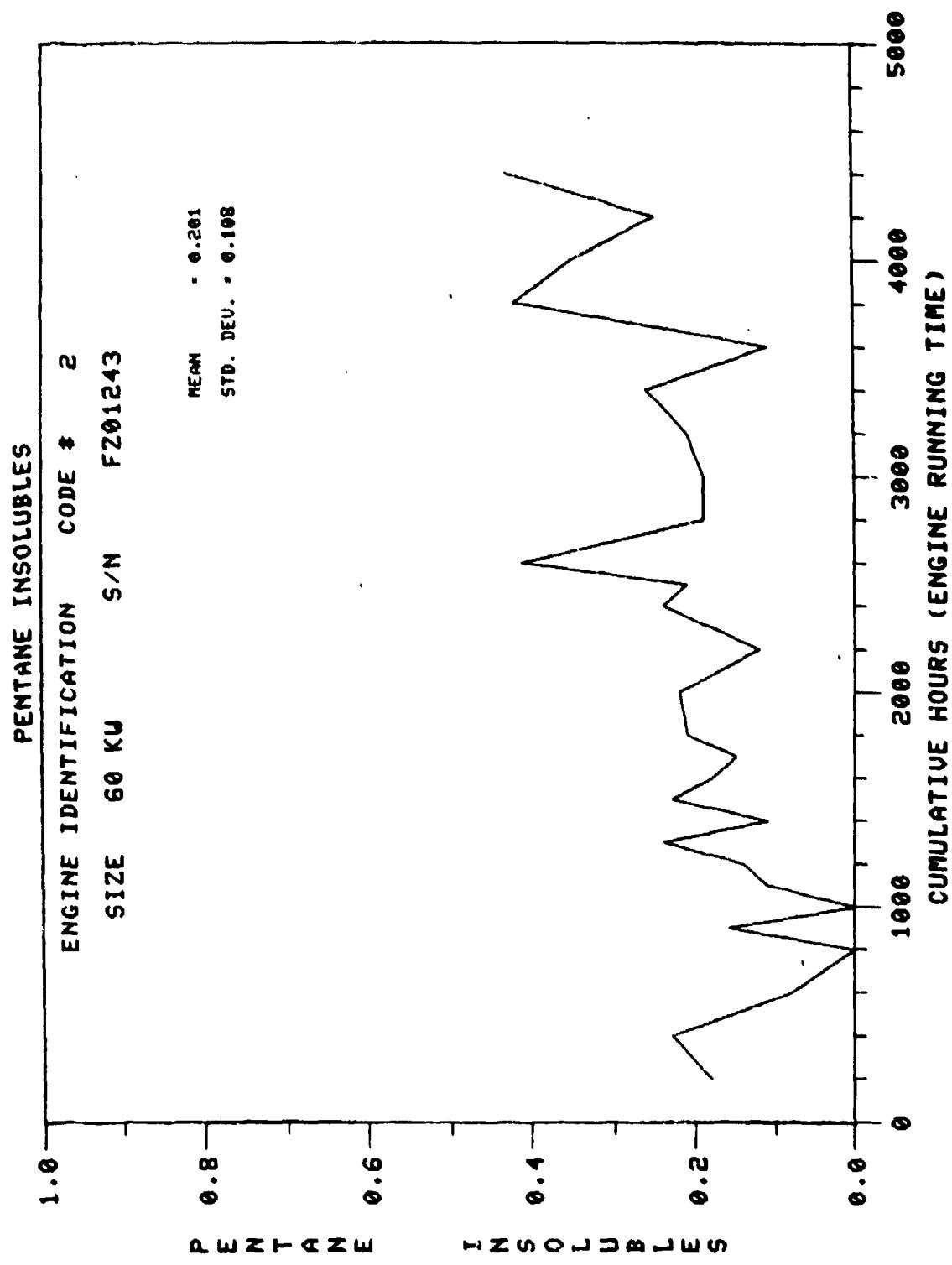


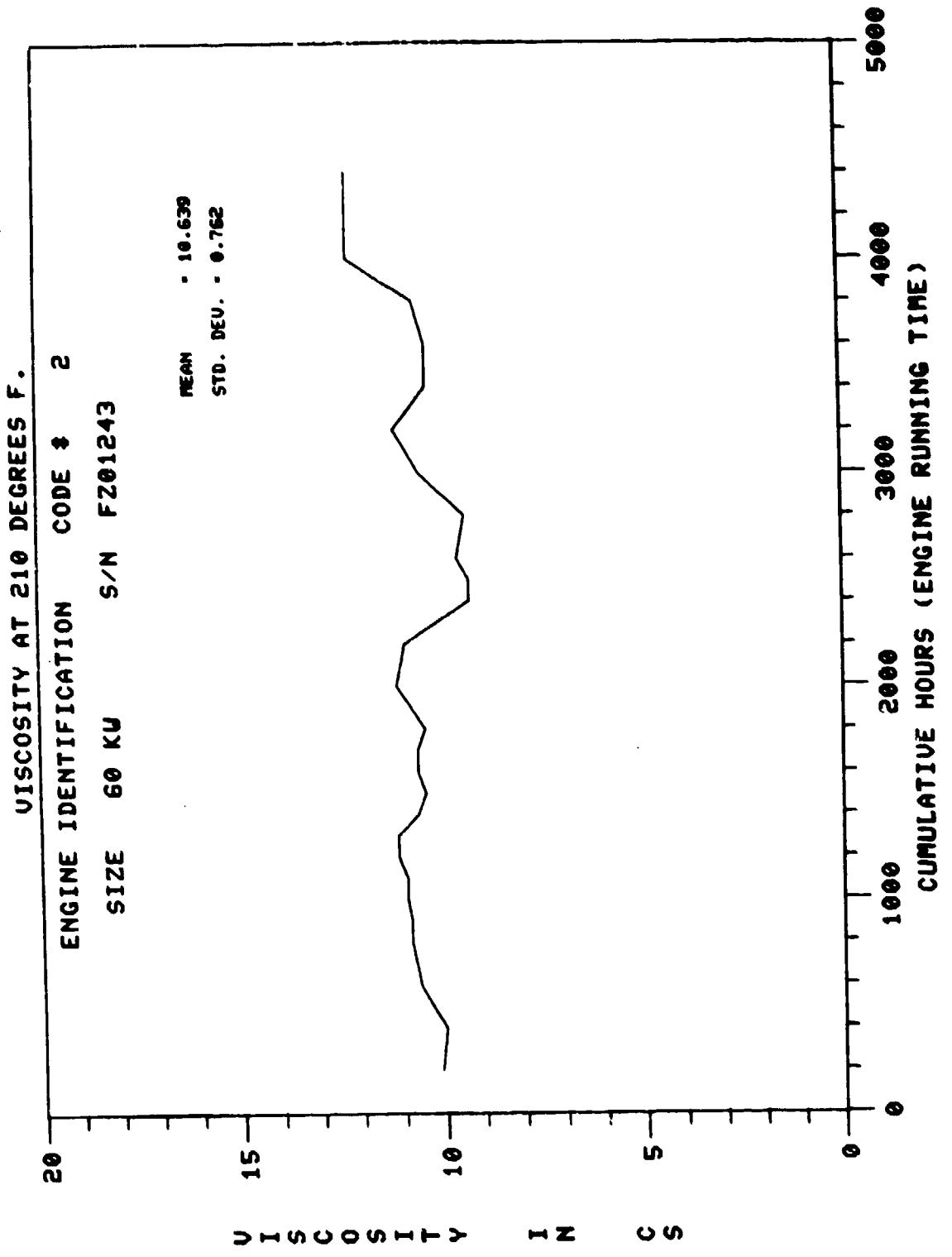












VISCOOSITY AT 100 DEGREES F.

ENGINE IDENTIFICATION CODE # 2

SIZE 60 KW S/N F201243

MEAN = 88.061
STD. DEV. = 7.649

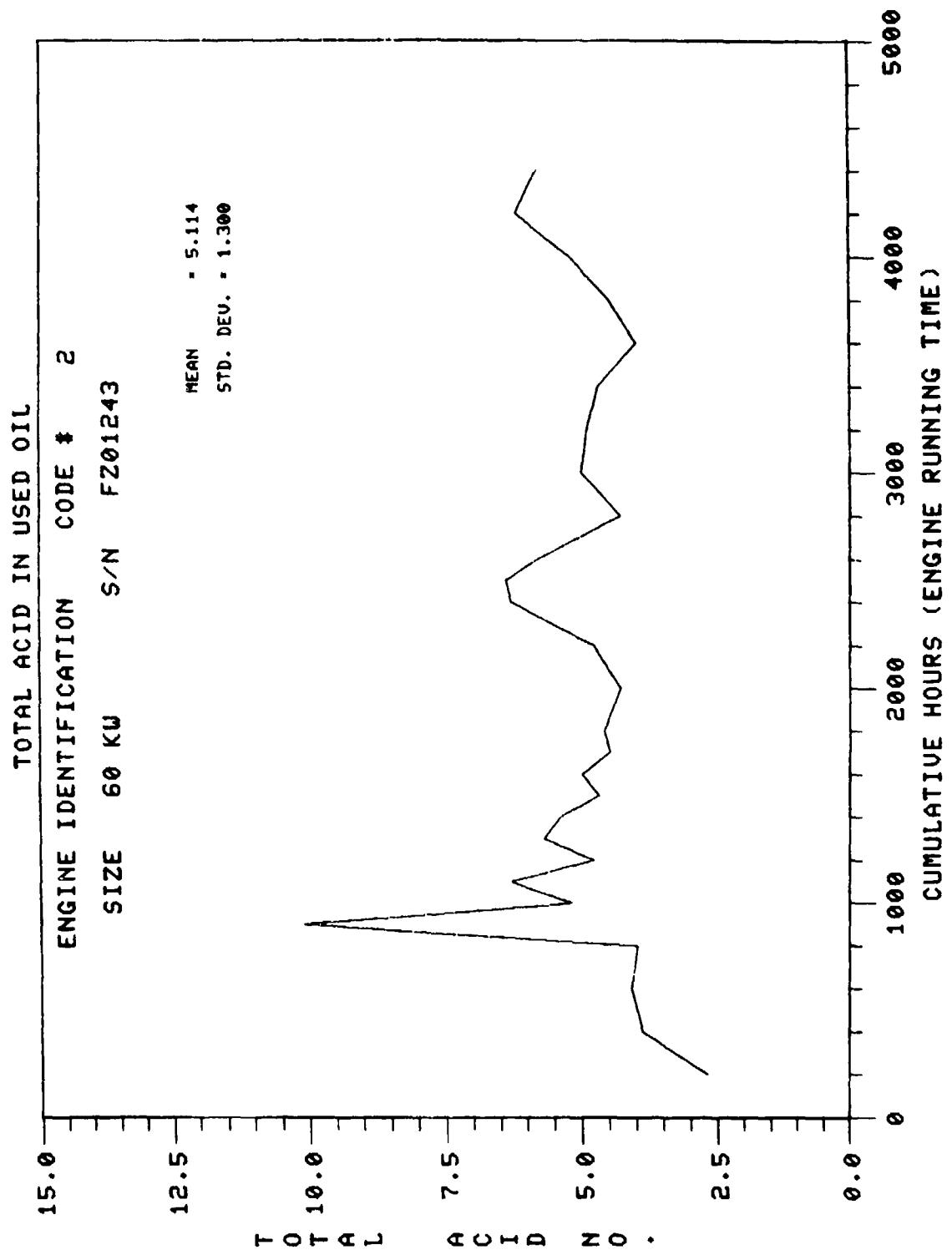
Y T I S C O S T I C U

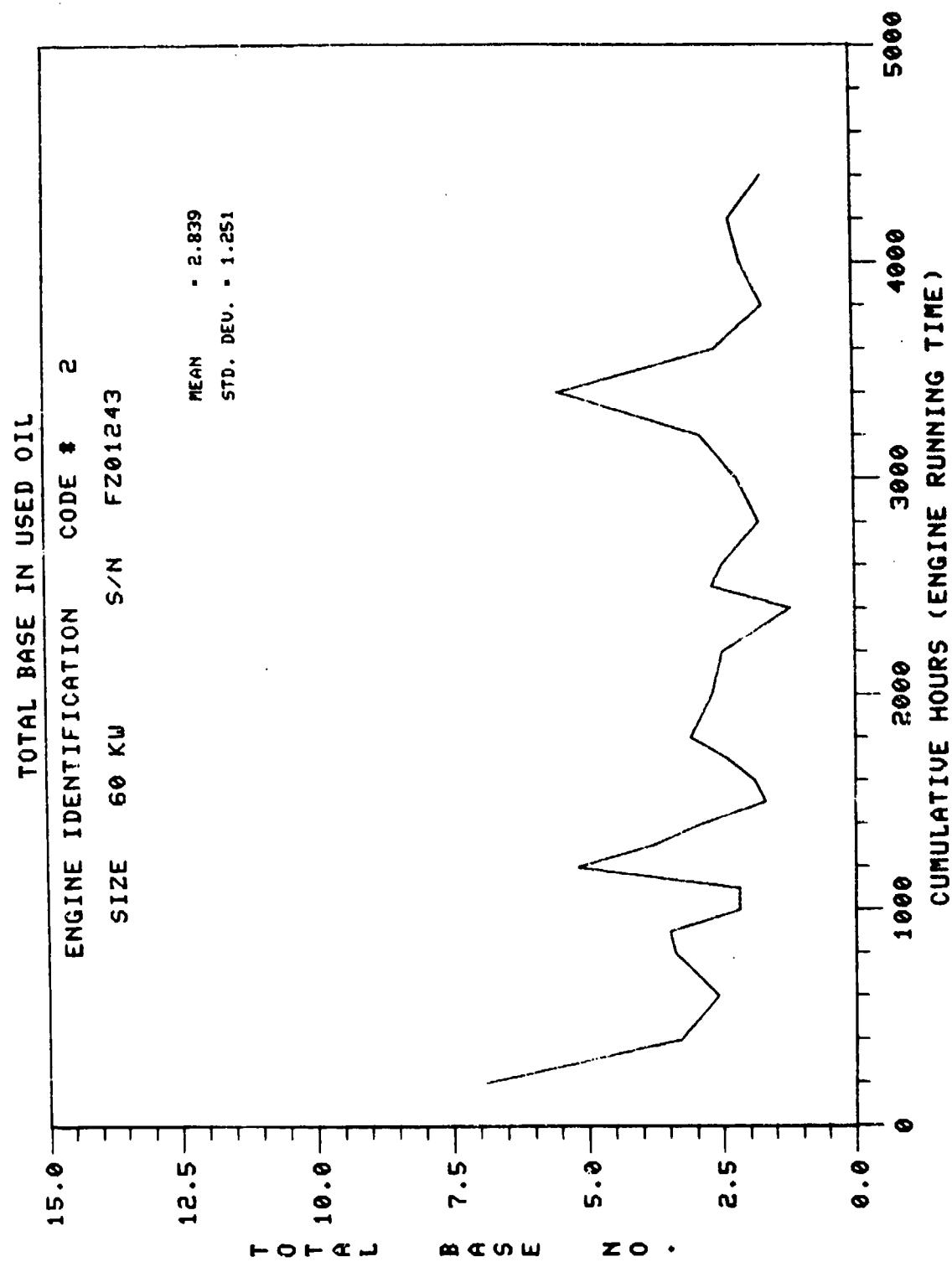
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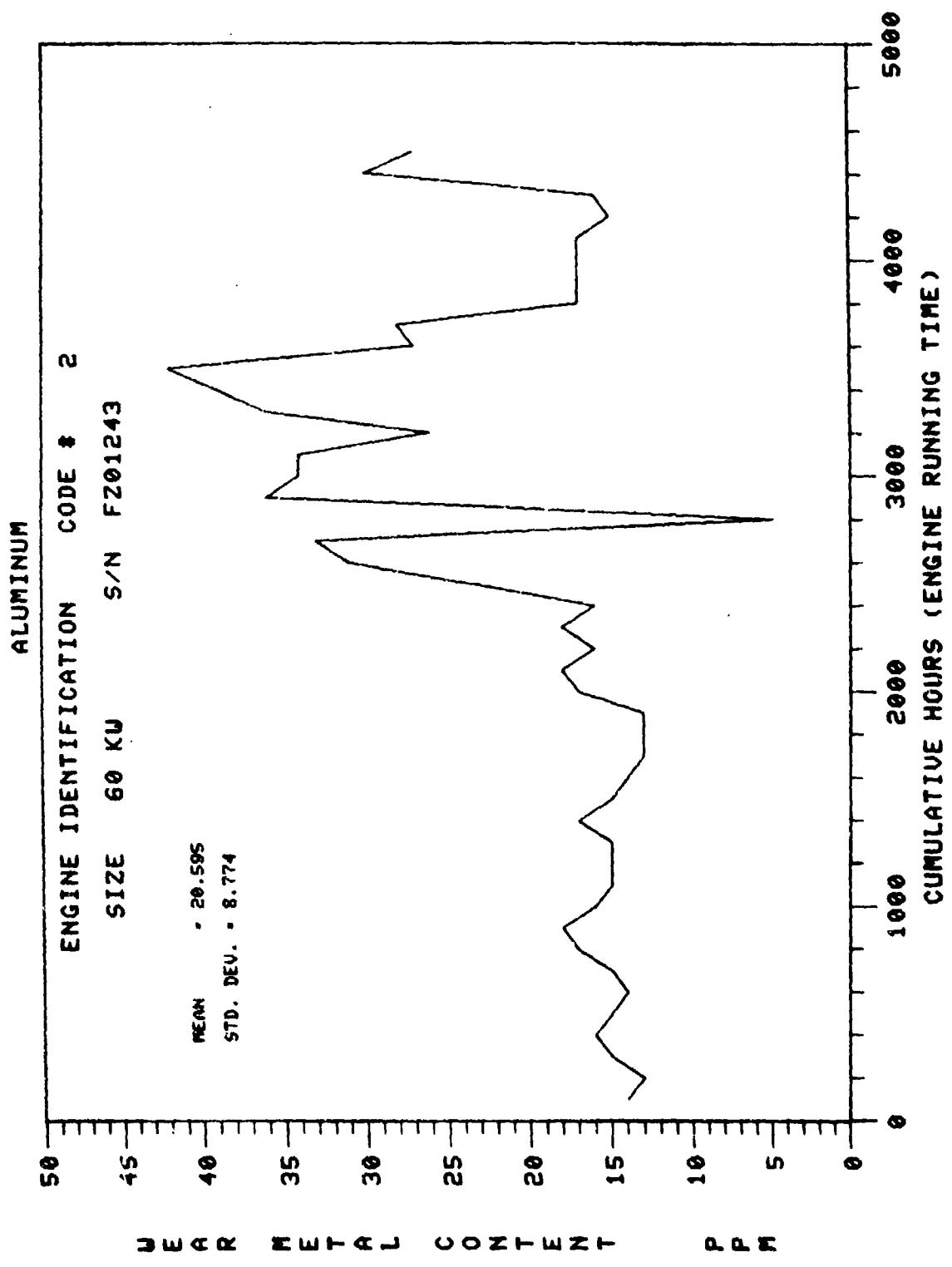
C S

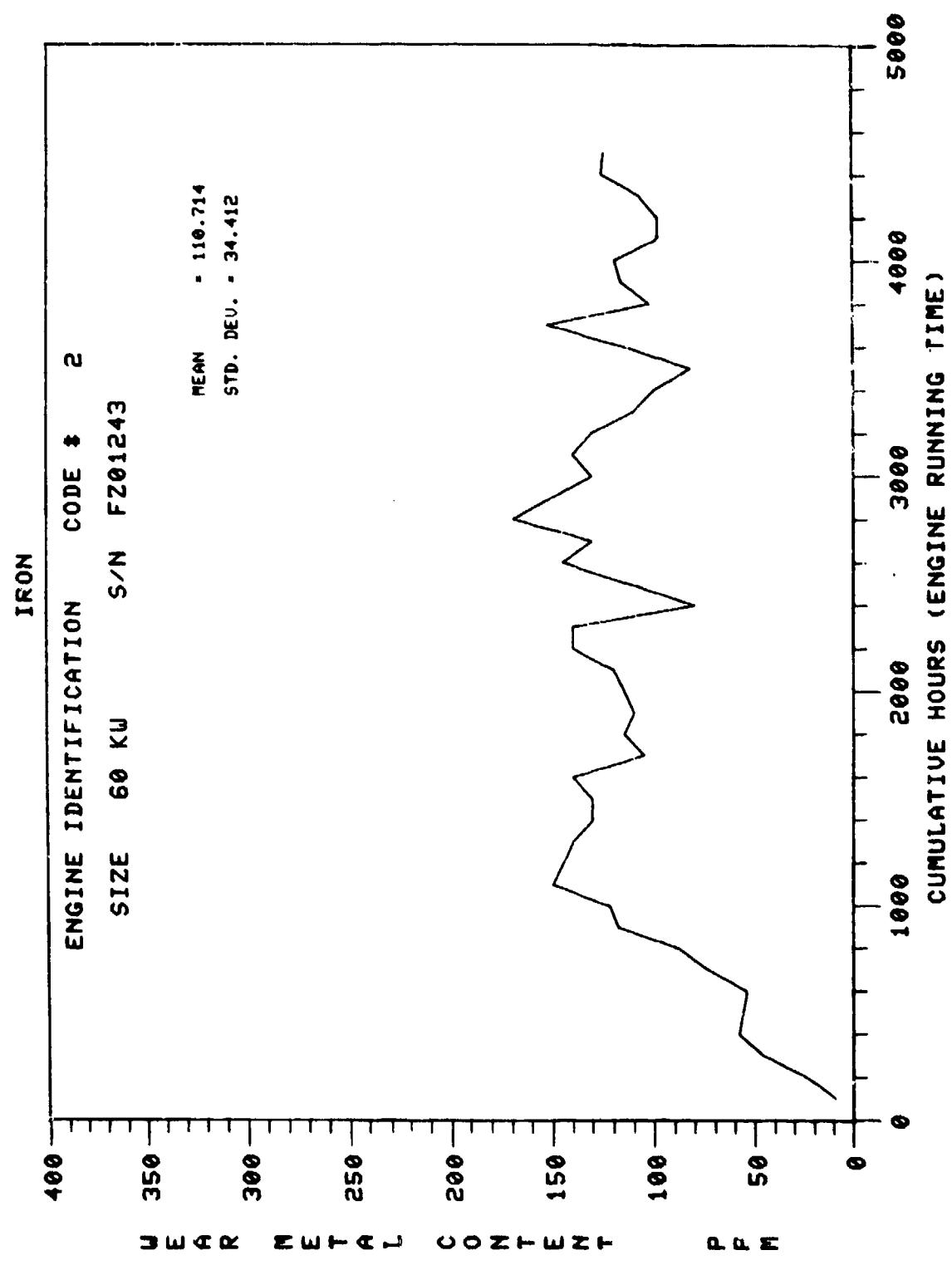
75 85

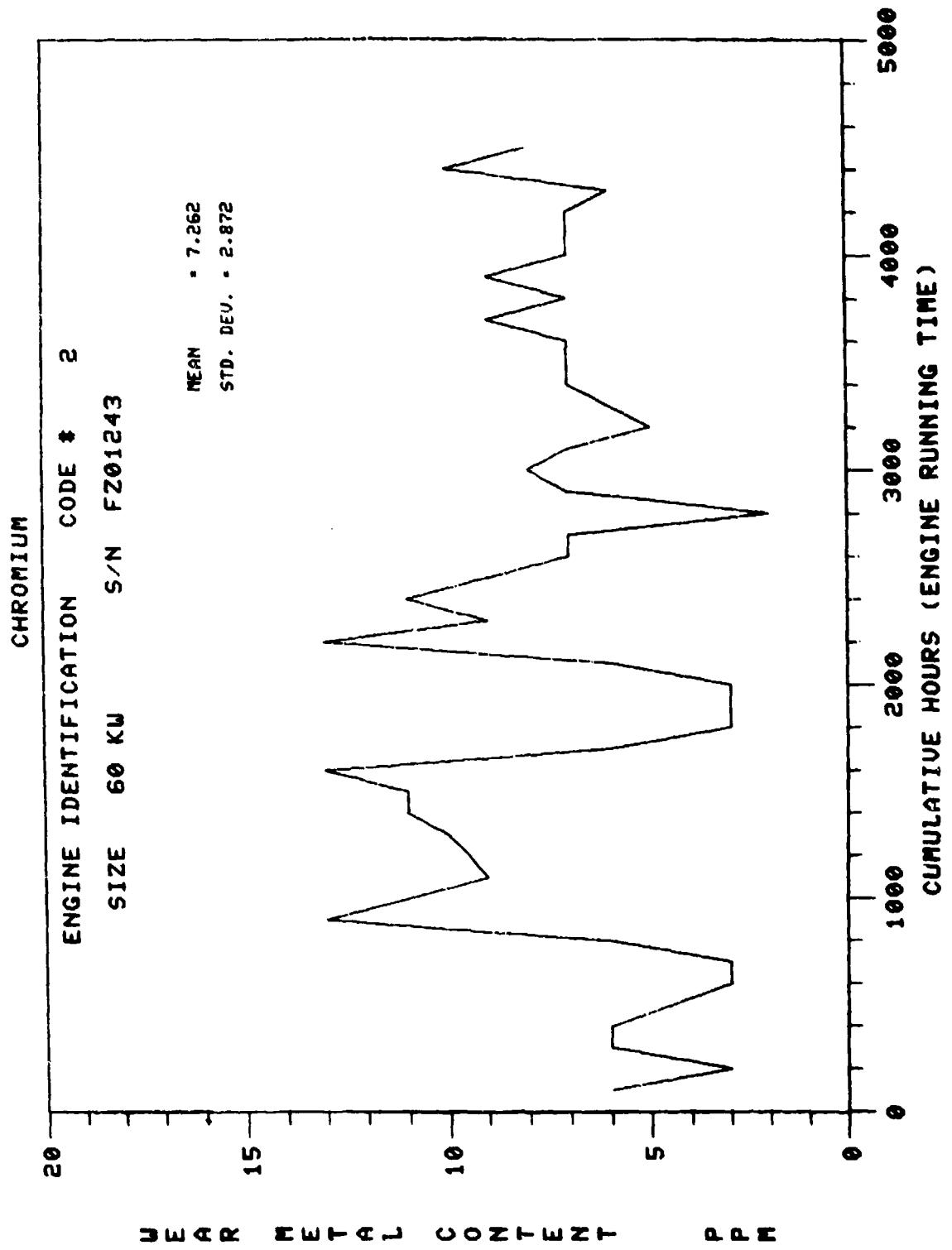
0 50 1000 2000 3000 4000 5000
CUMULATIVE HOURS (ENGINE RUNNING TIME)

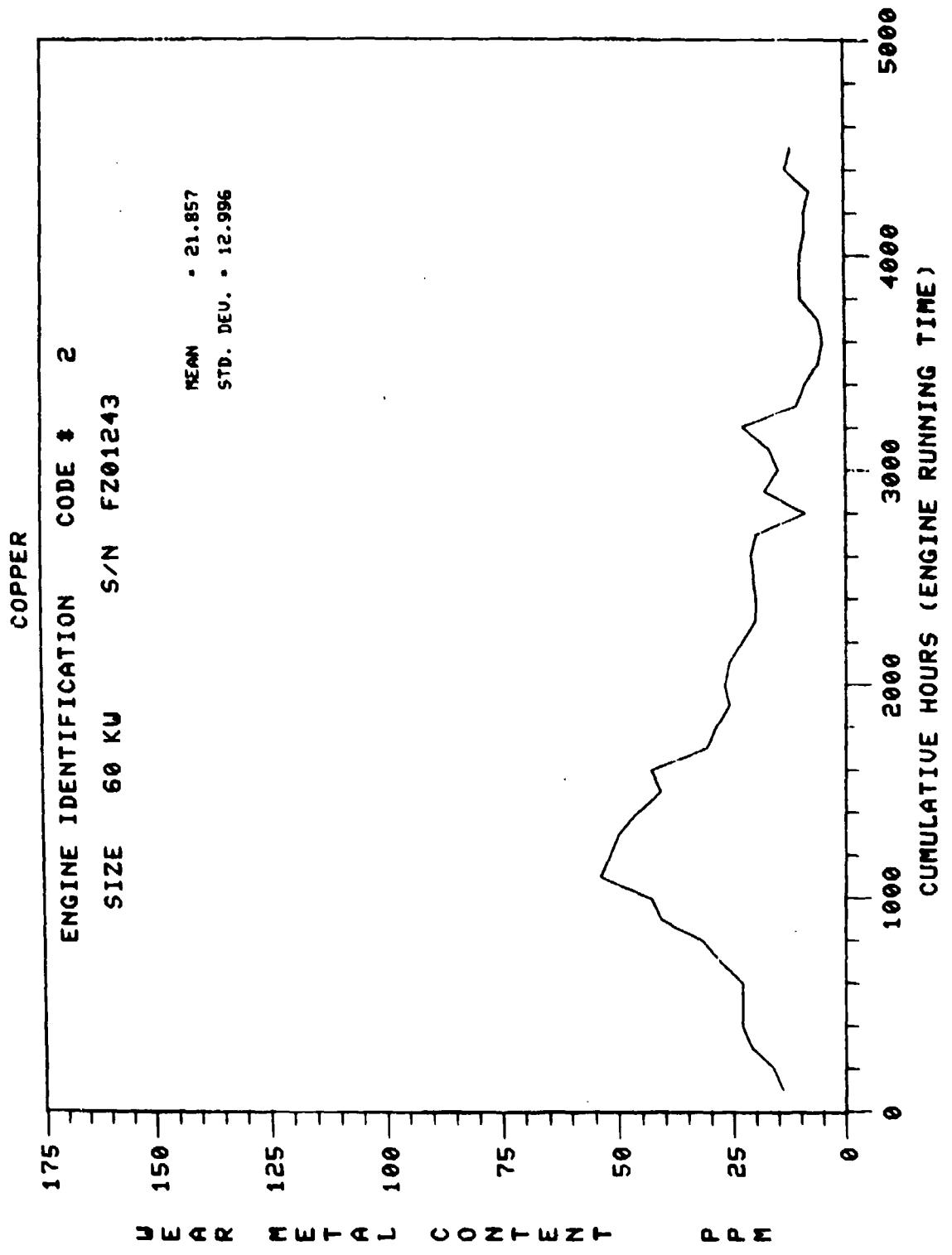


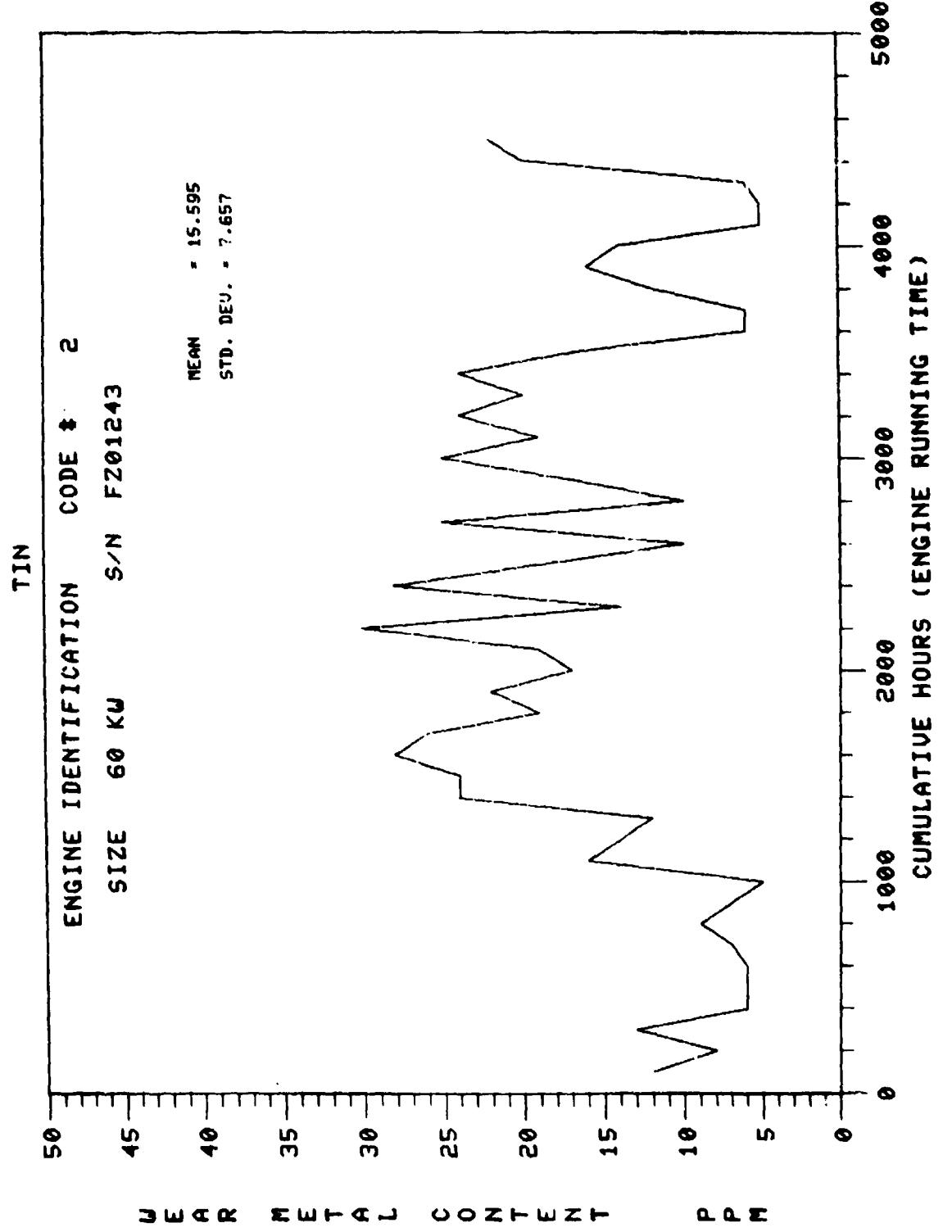


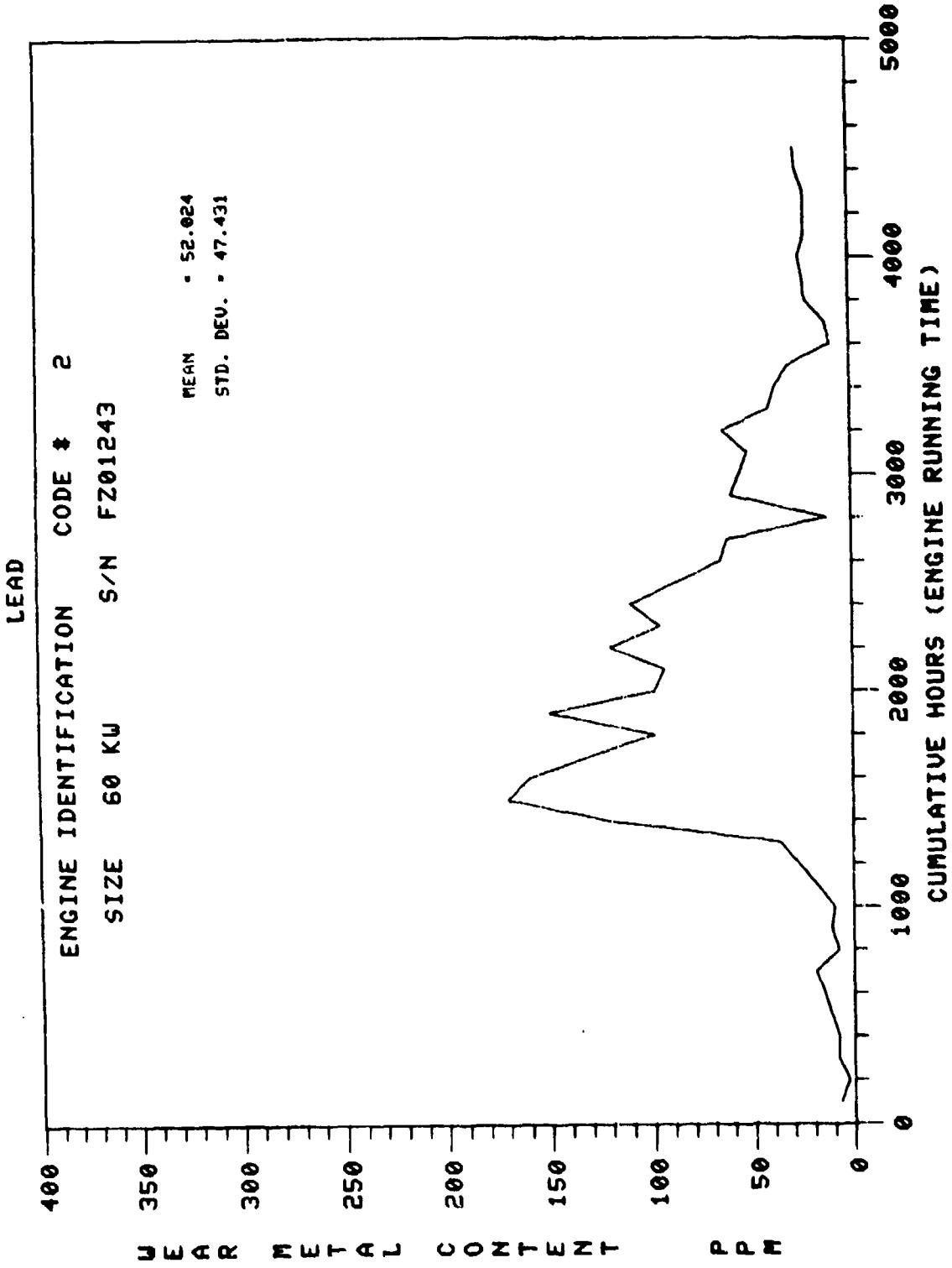


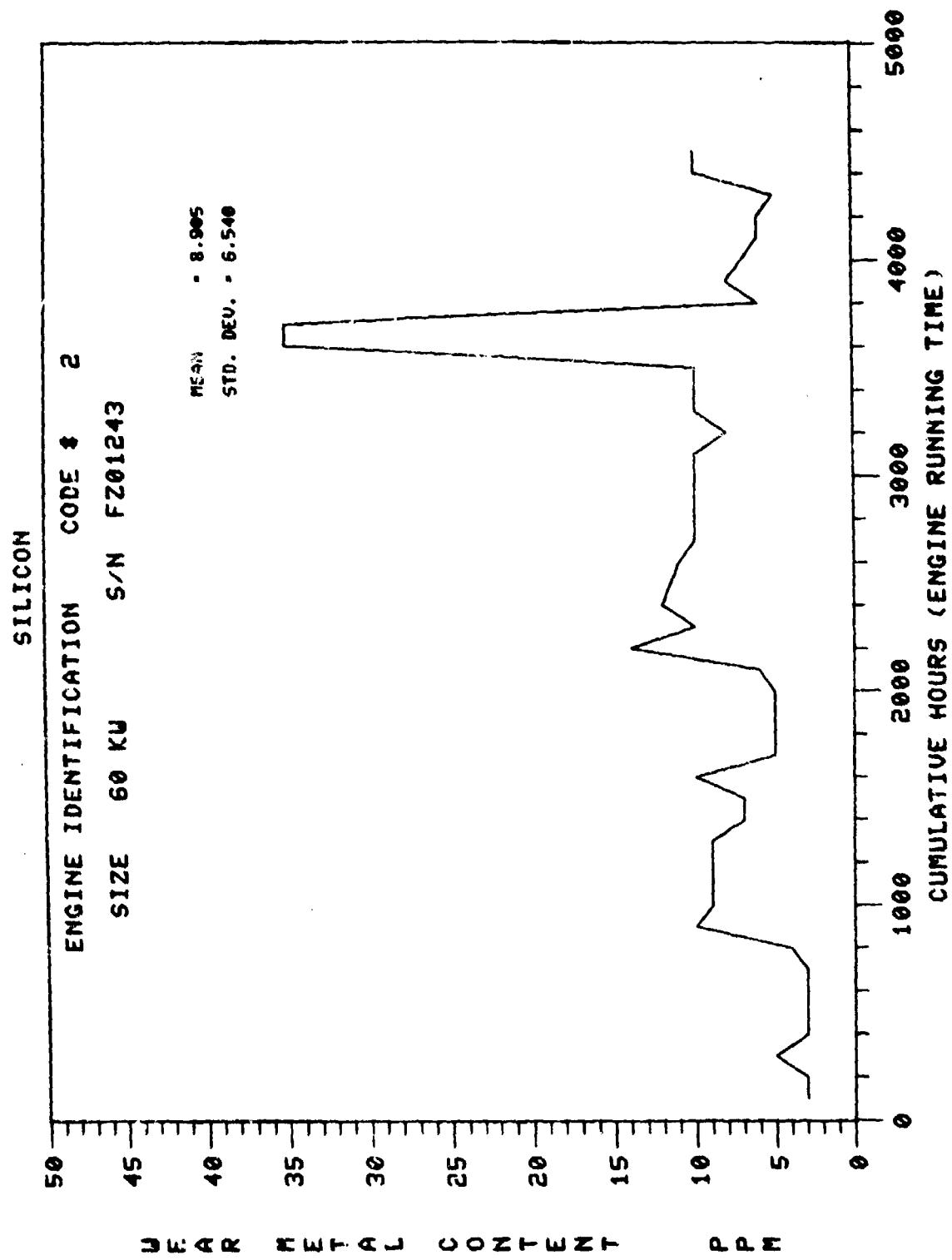


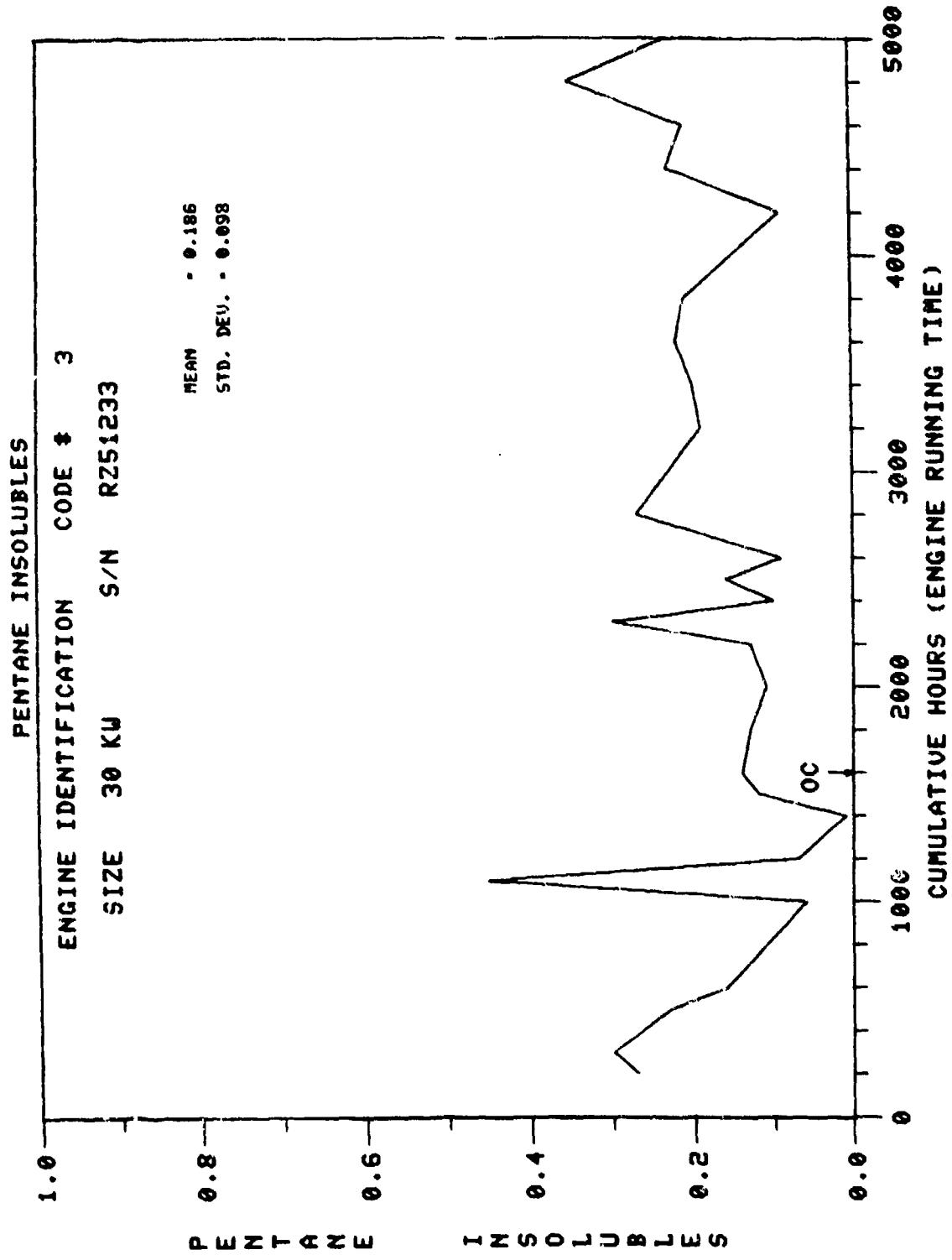


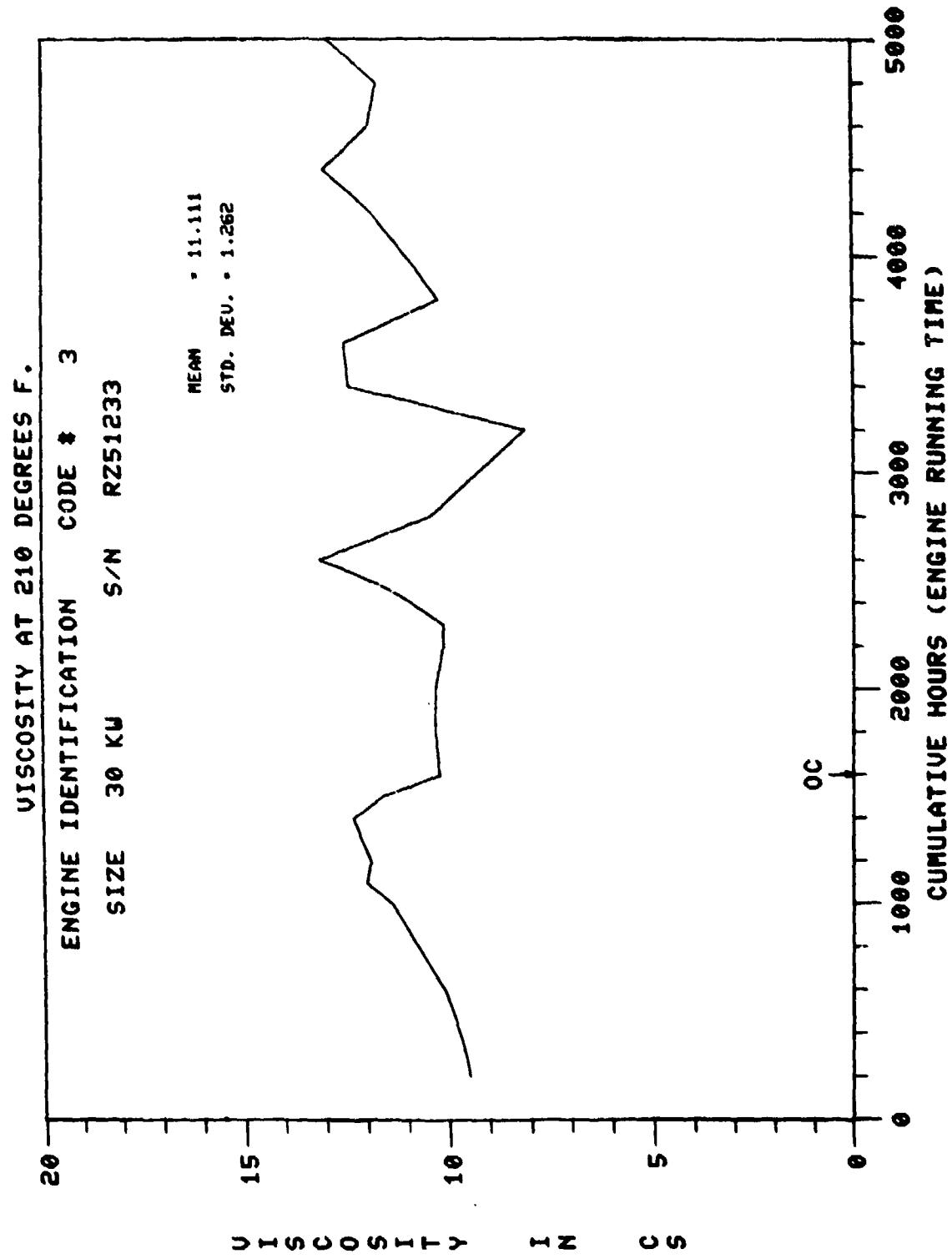












VISCOSITY AT 100 DEGREES F.

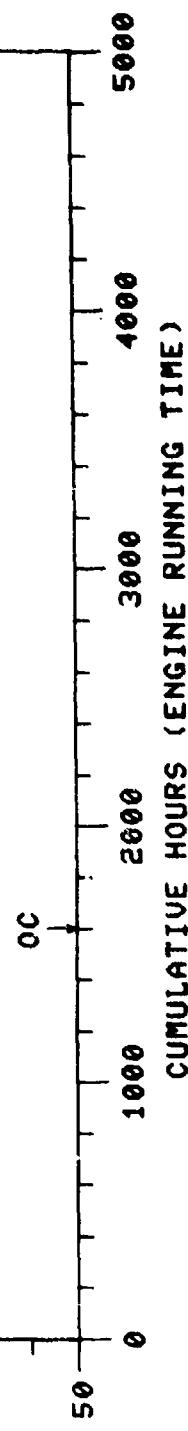
ENGINE IDENTIFICATION CODE # 3

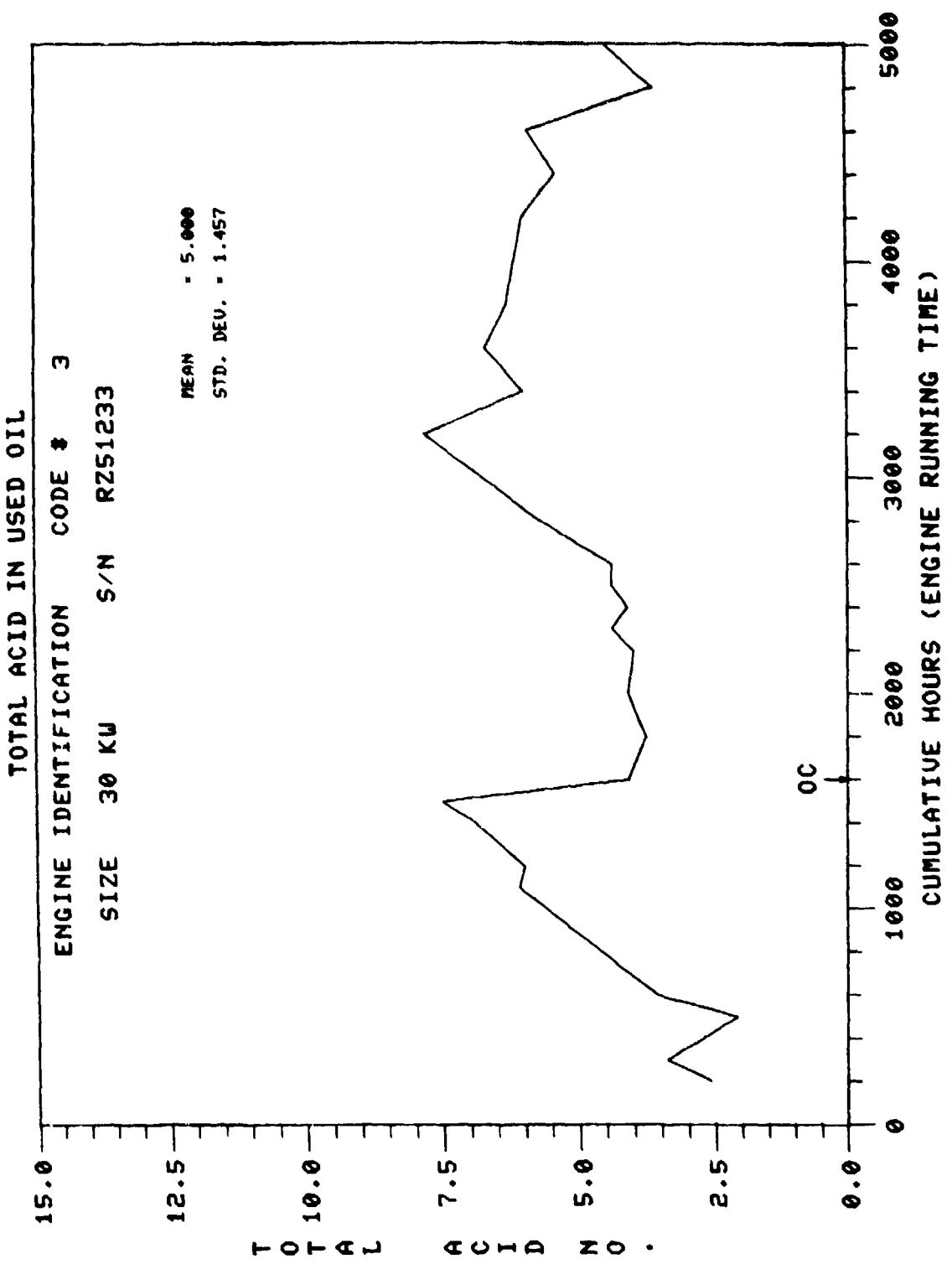
SIZE 30 KW S/N RZ51233

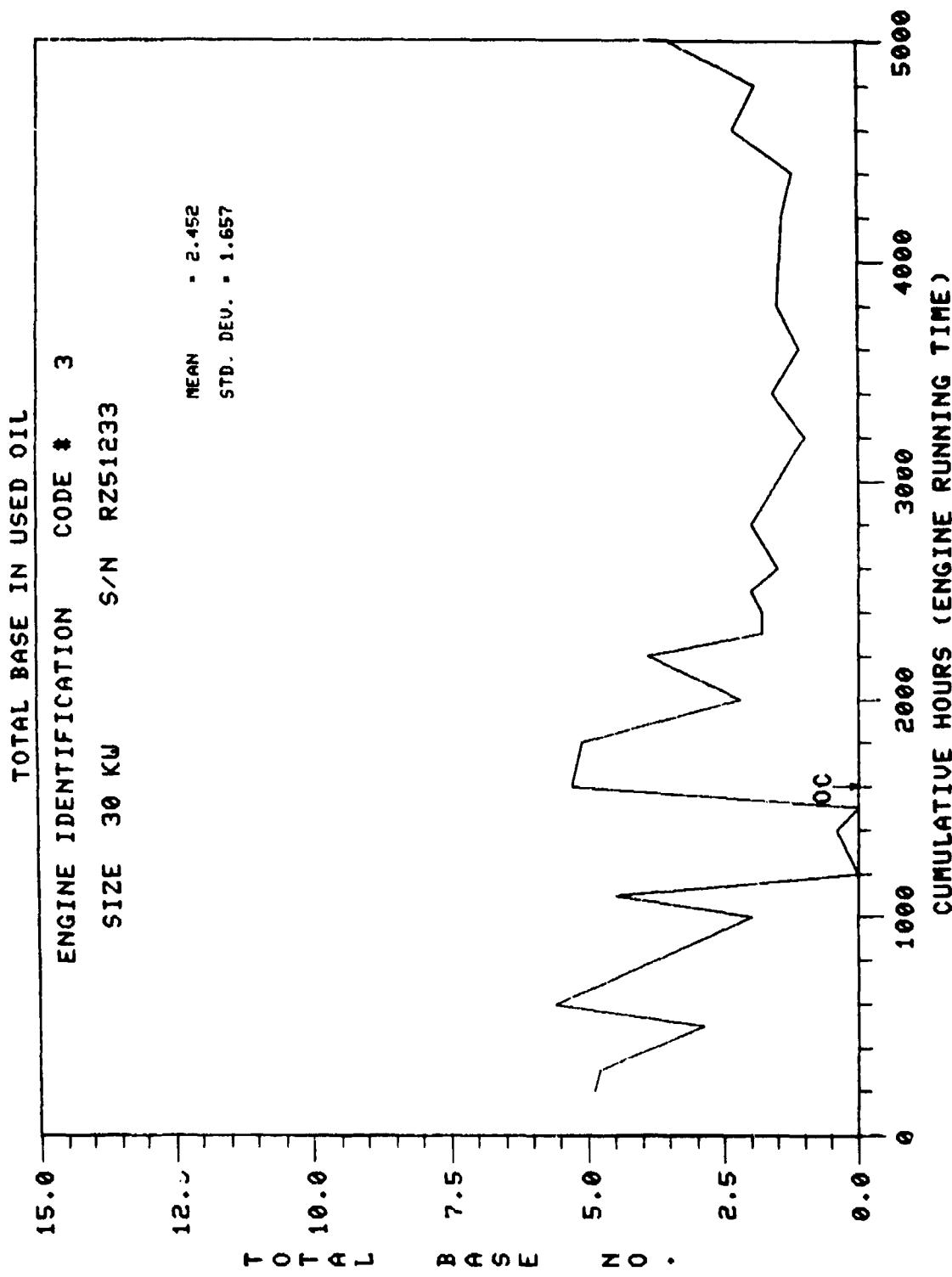
MEAN = 87.967
STD. DEV. = 10.333

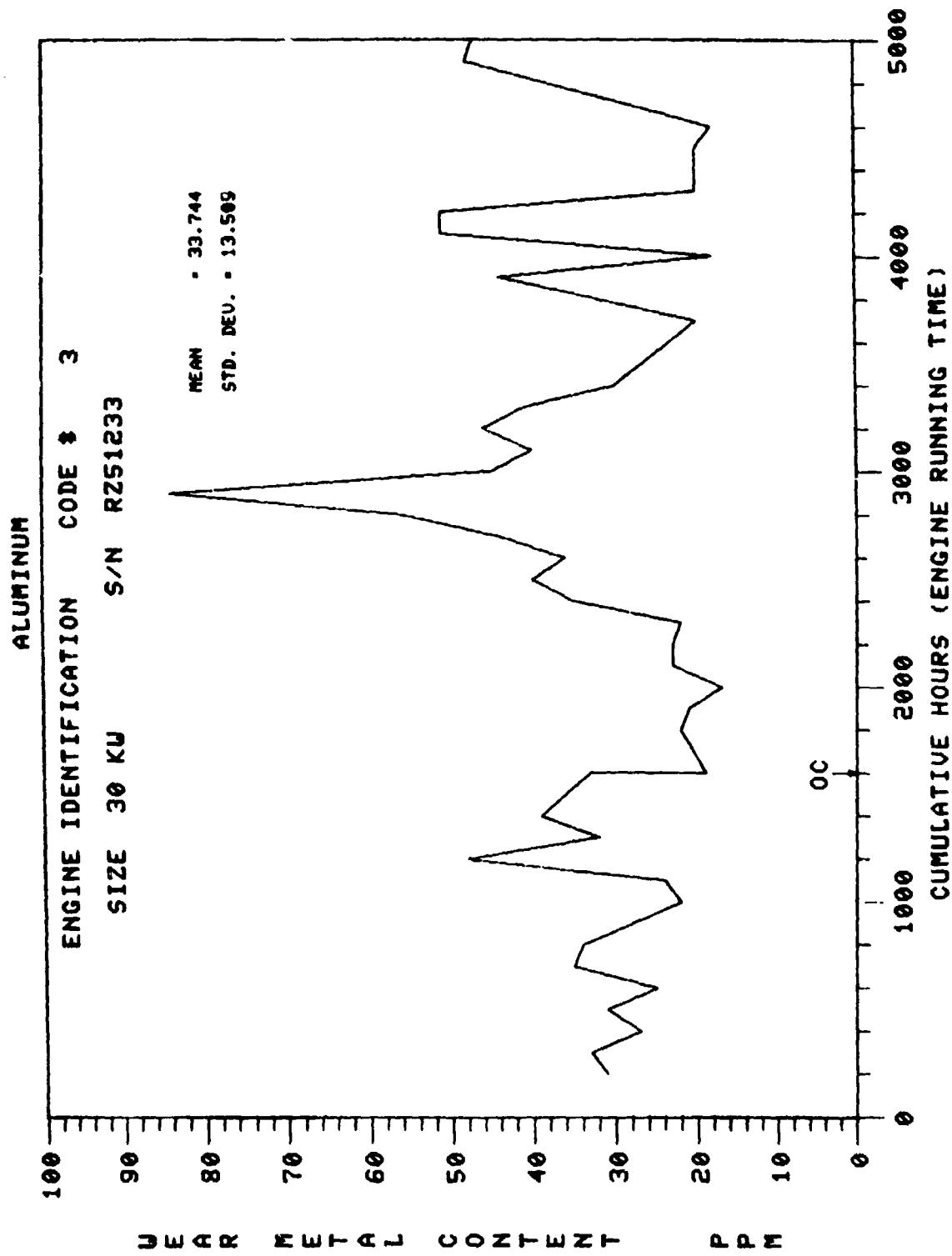
U I S C O S I T Y

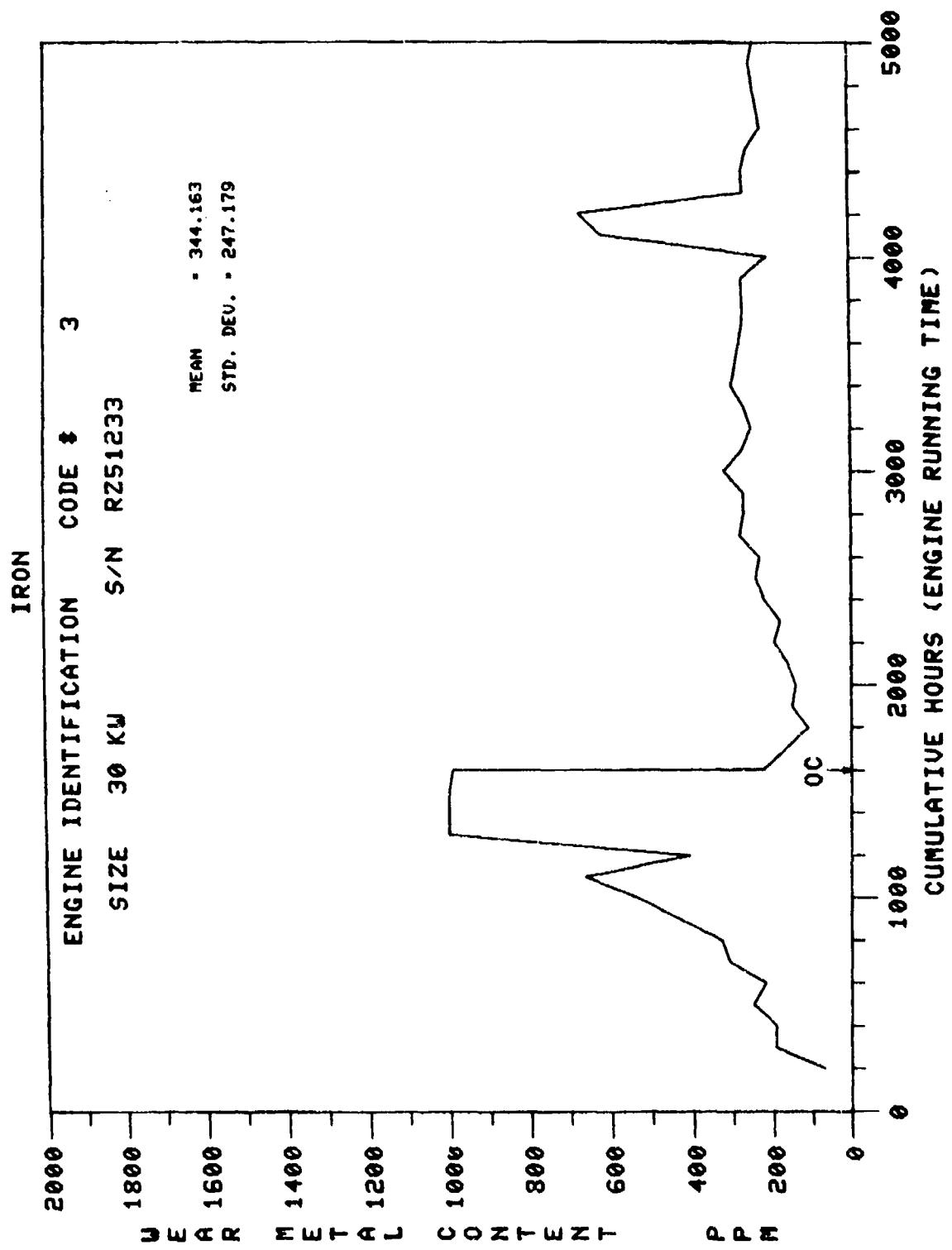
C S







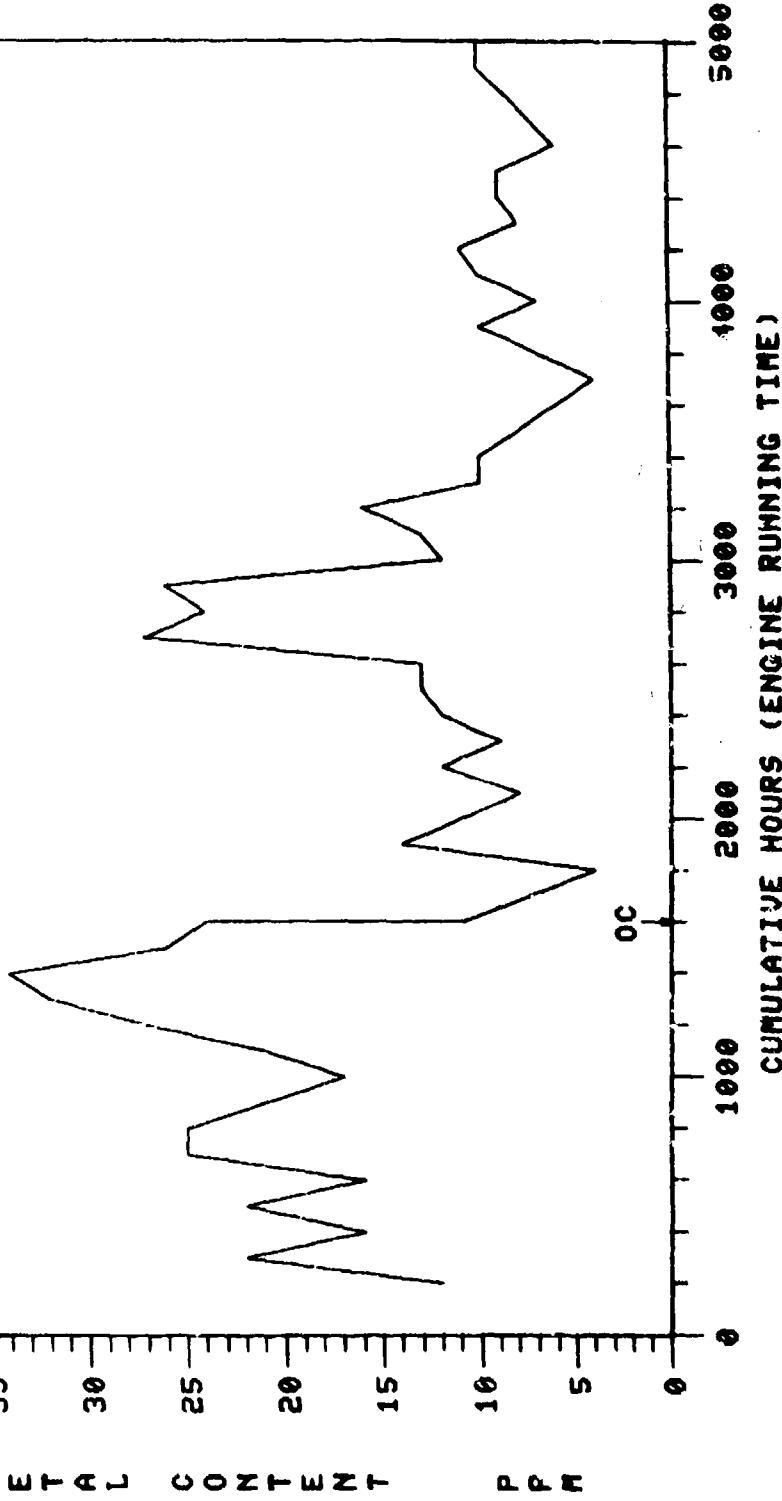




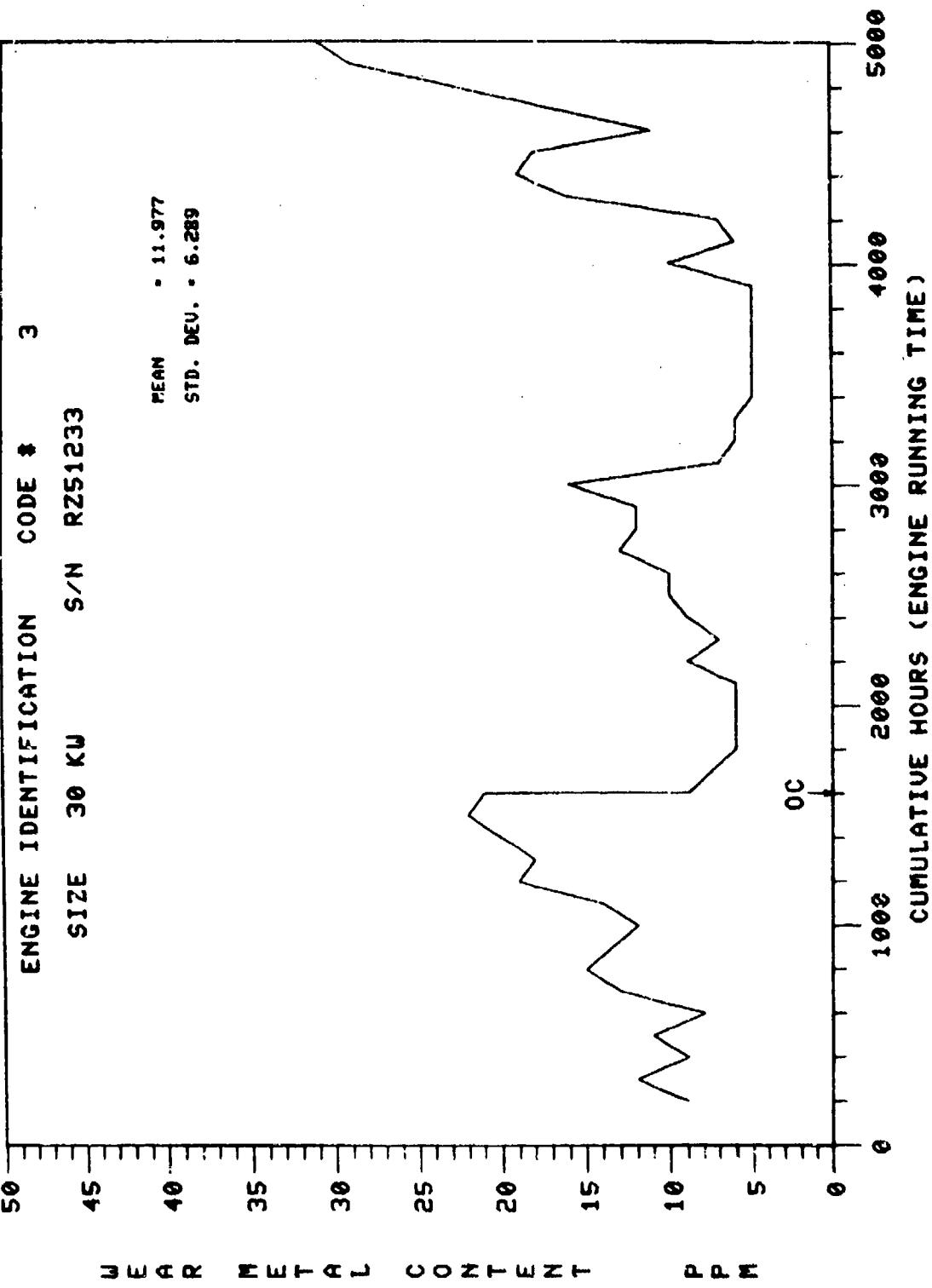
CHROMIUM

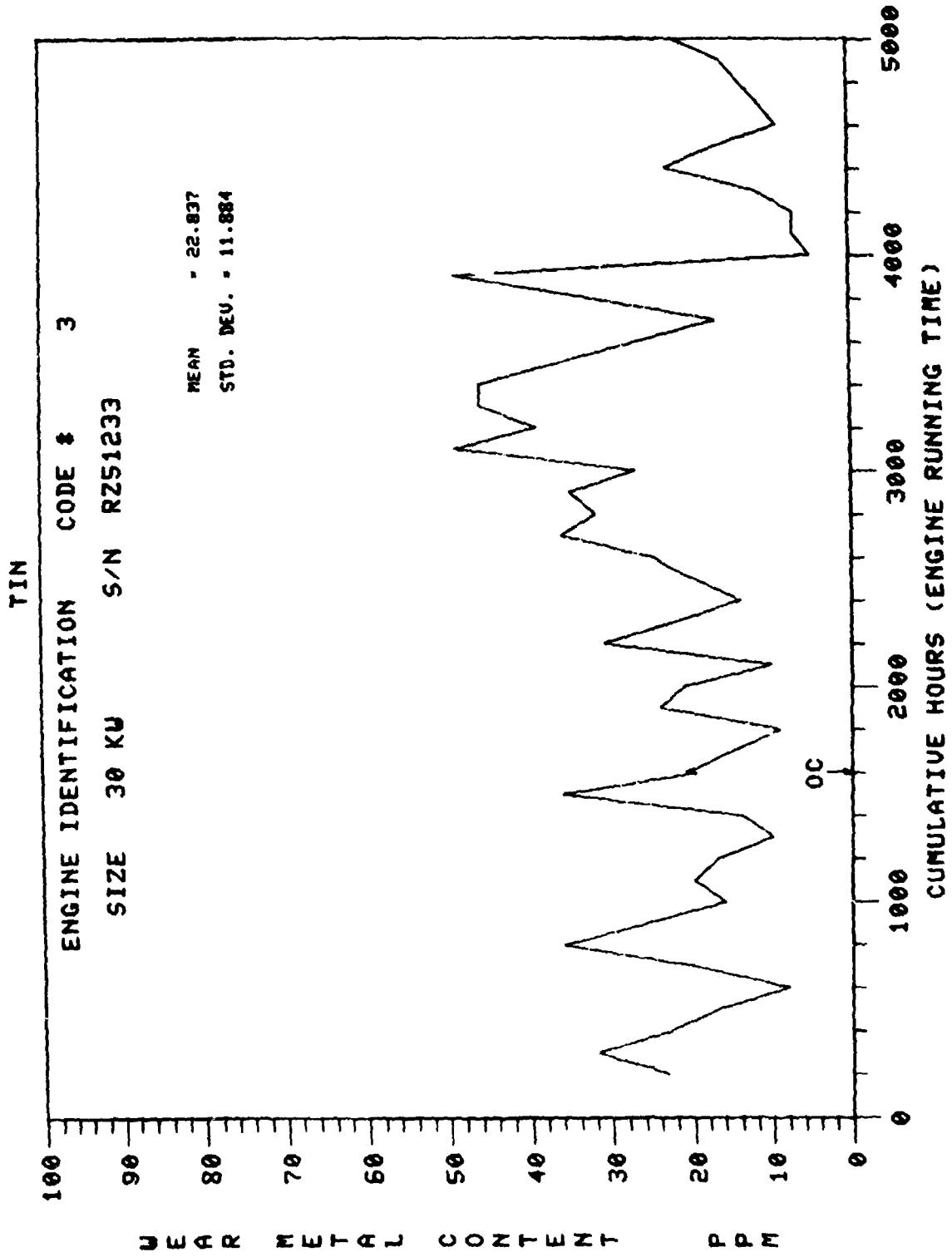
58 ENGINE IDENTIFICATION CODE # 3
SIZE 30 KH S/N RZ51233

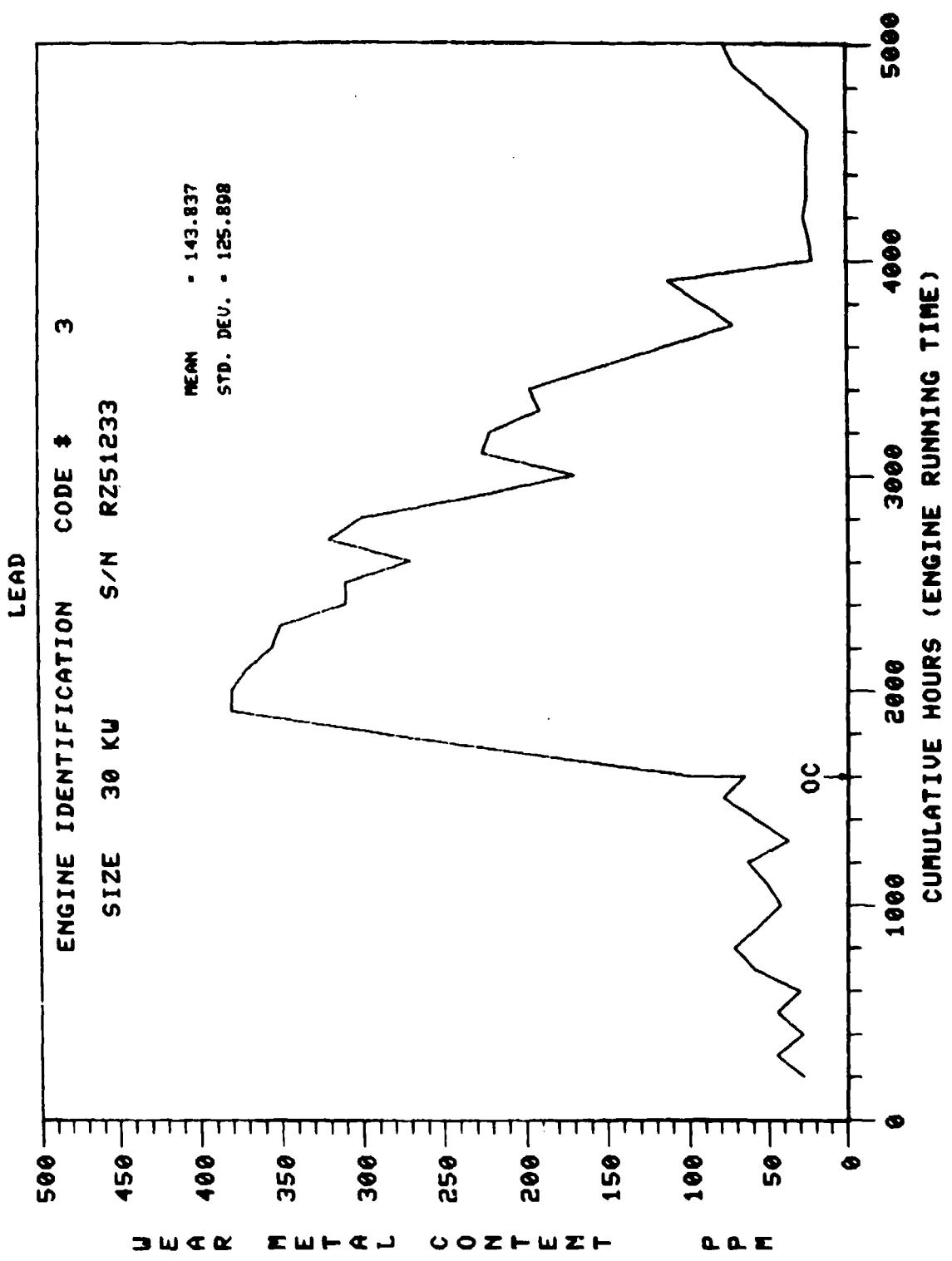
MEAN = 15.302
STD. DEV. = 7.745

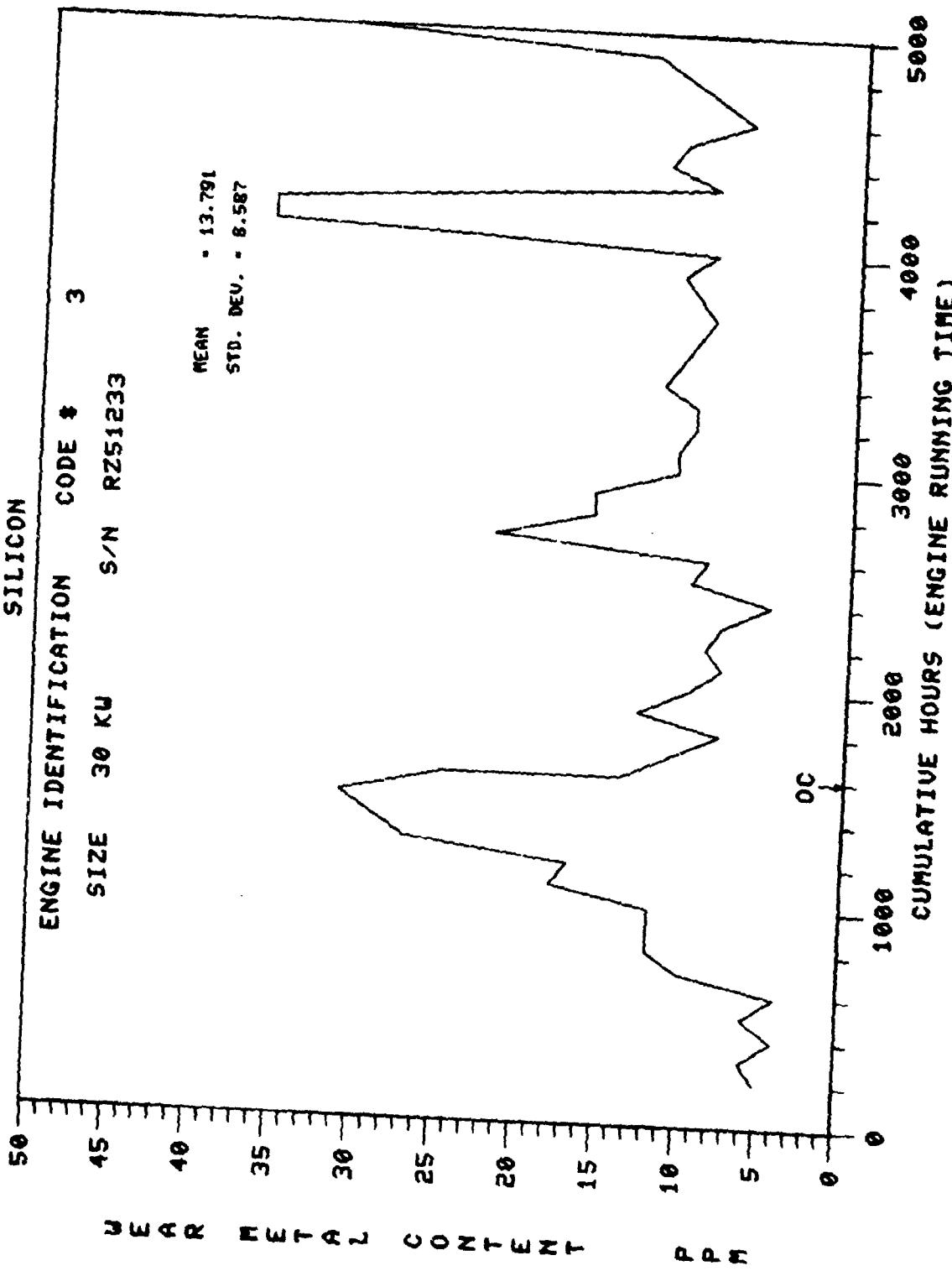


COPPER





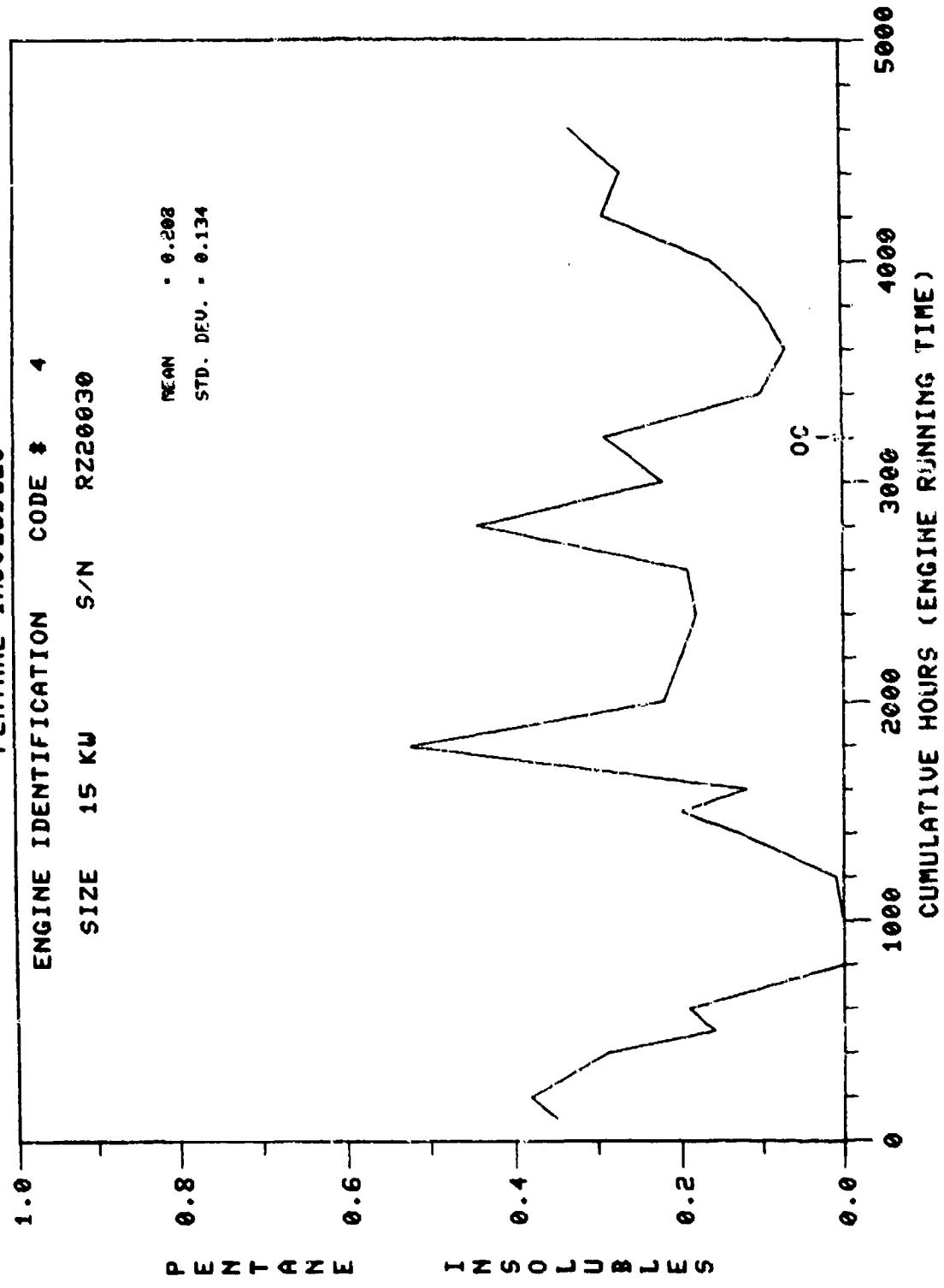


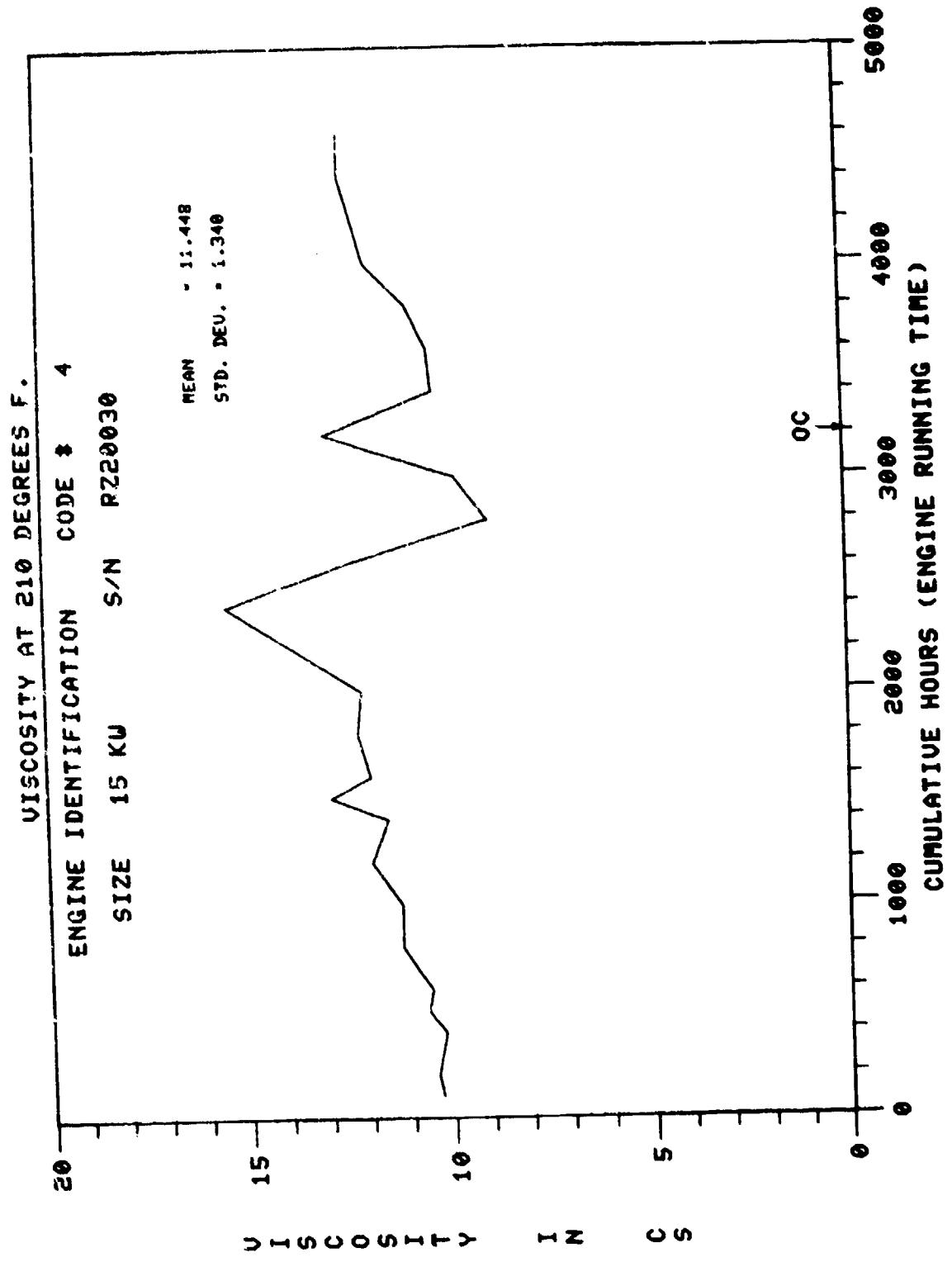


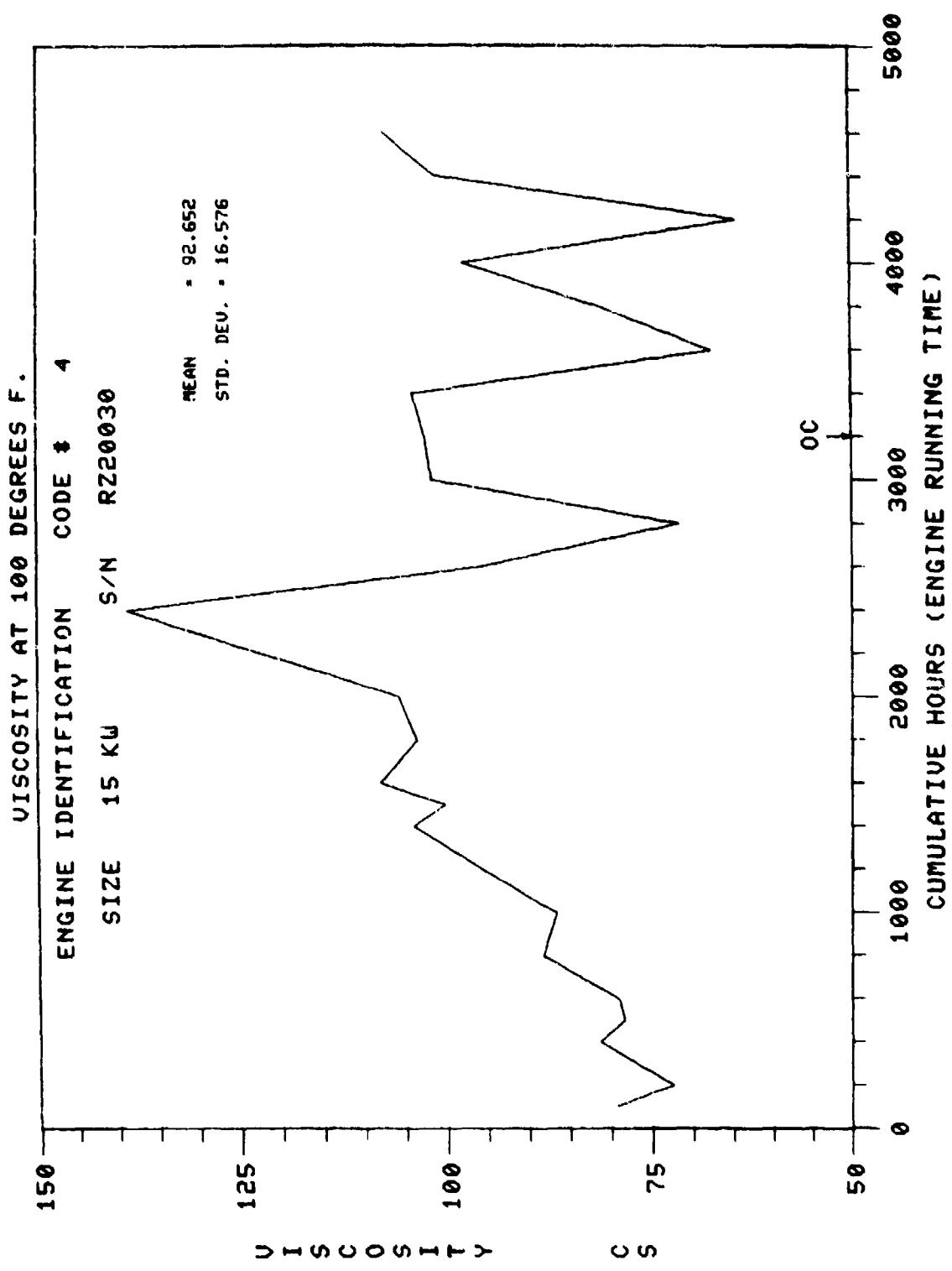
PENTANE INSOLUBLES

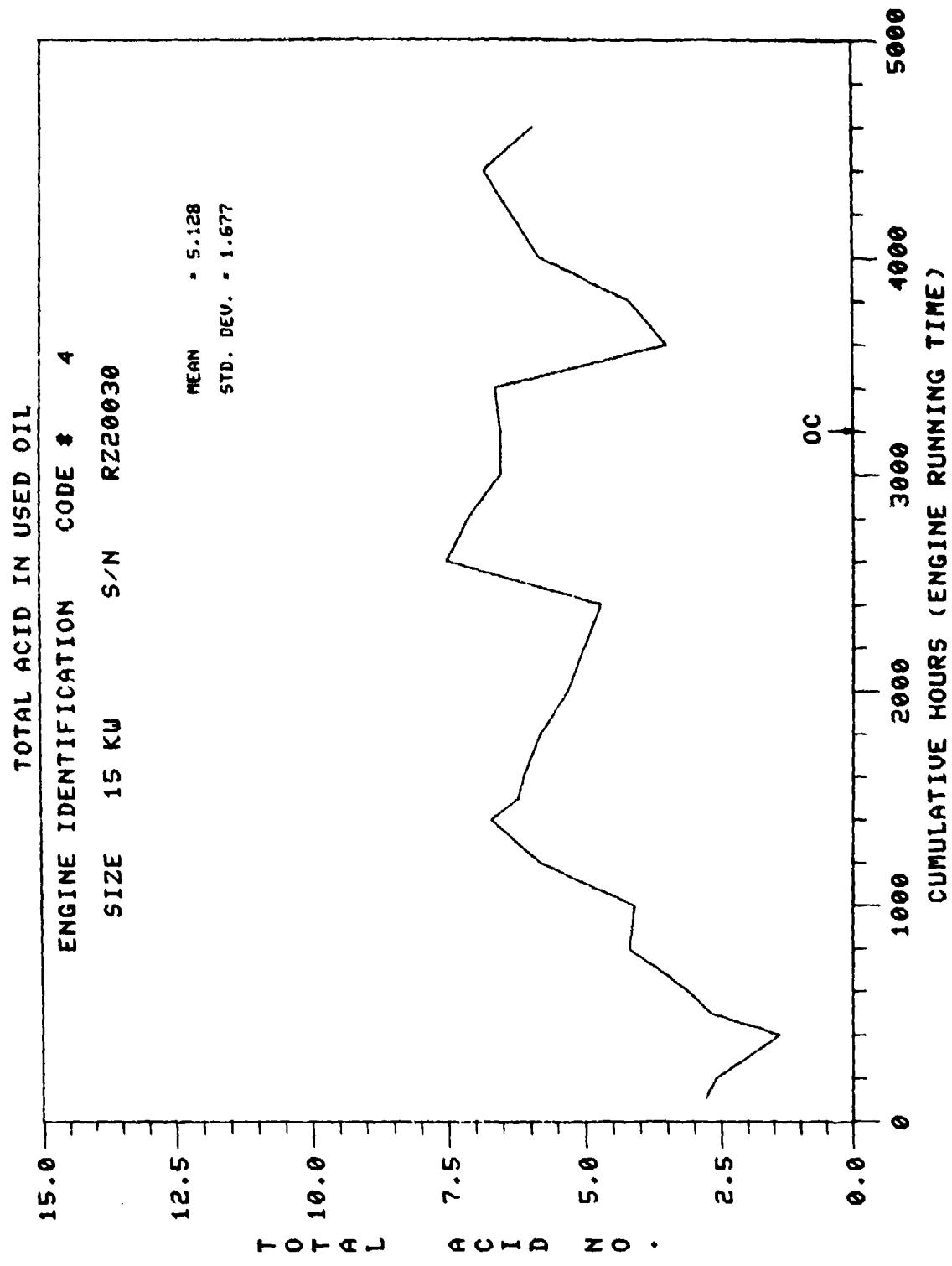
ENGINE IDENTIFICATION CODE # 4
SIZE 15 KU S/N RZ26030

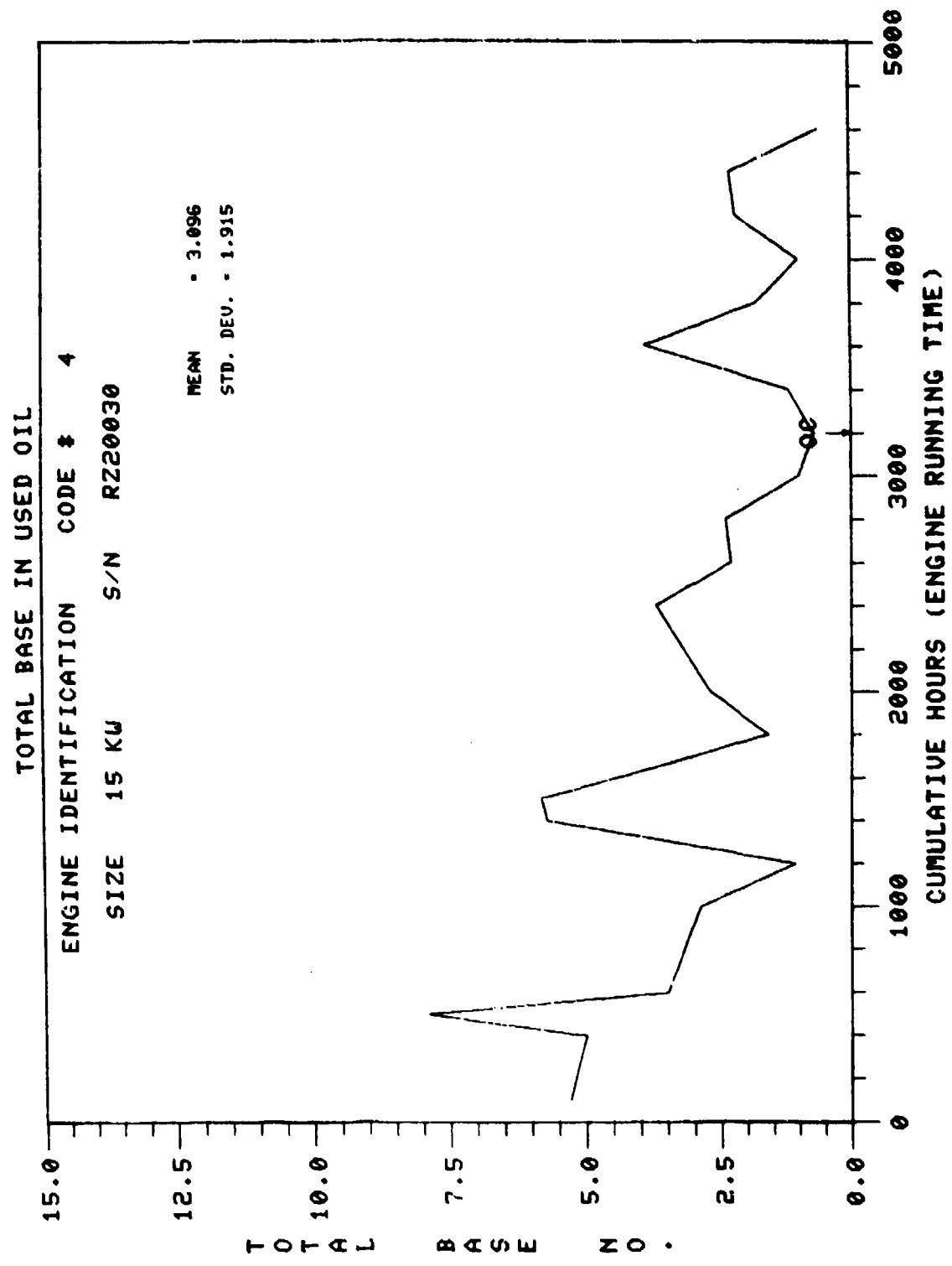
MEAN = 0.208
STD. DEV. = 0.134

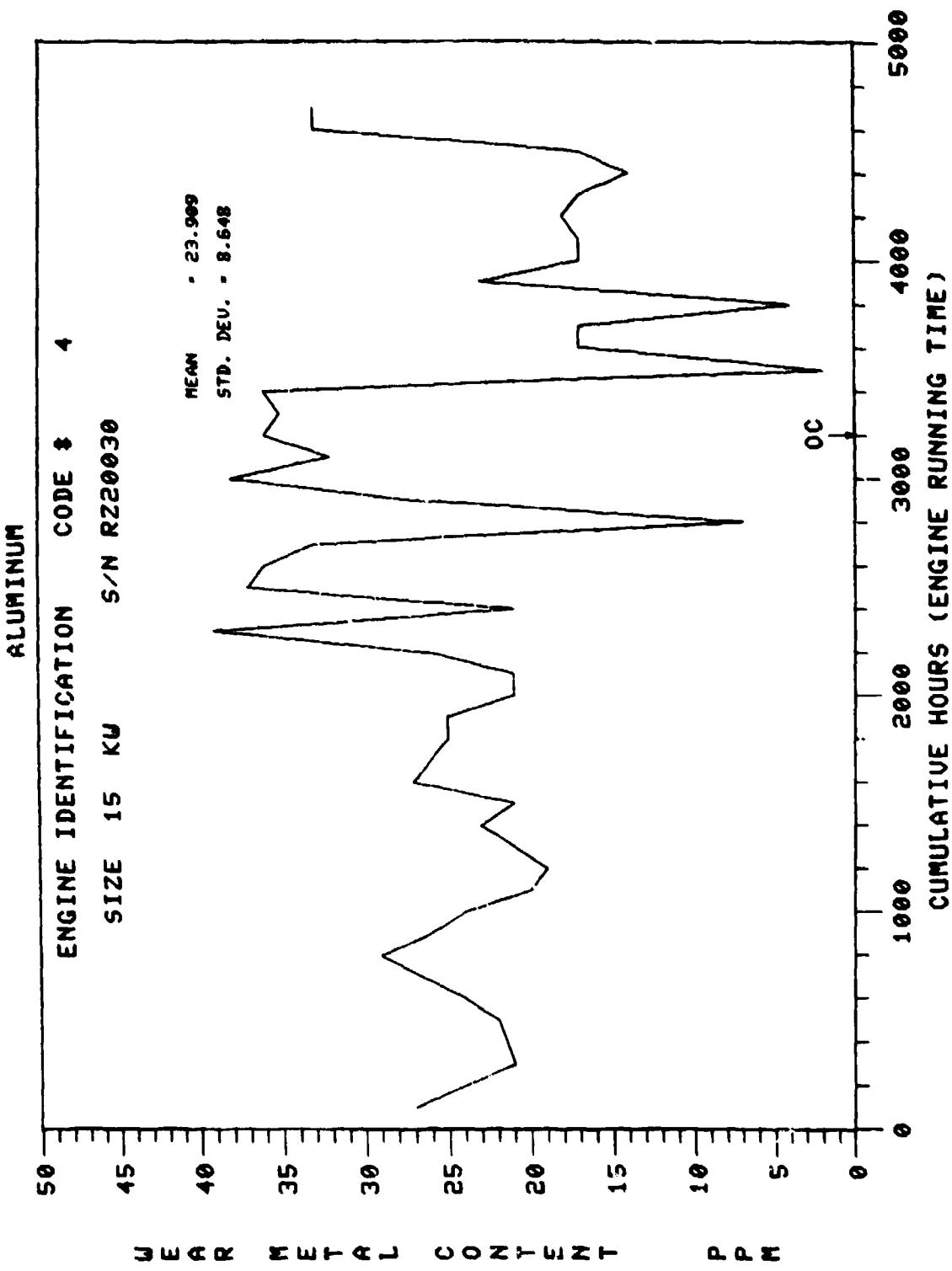


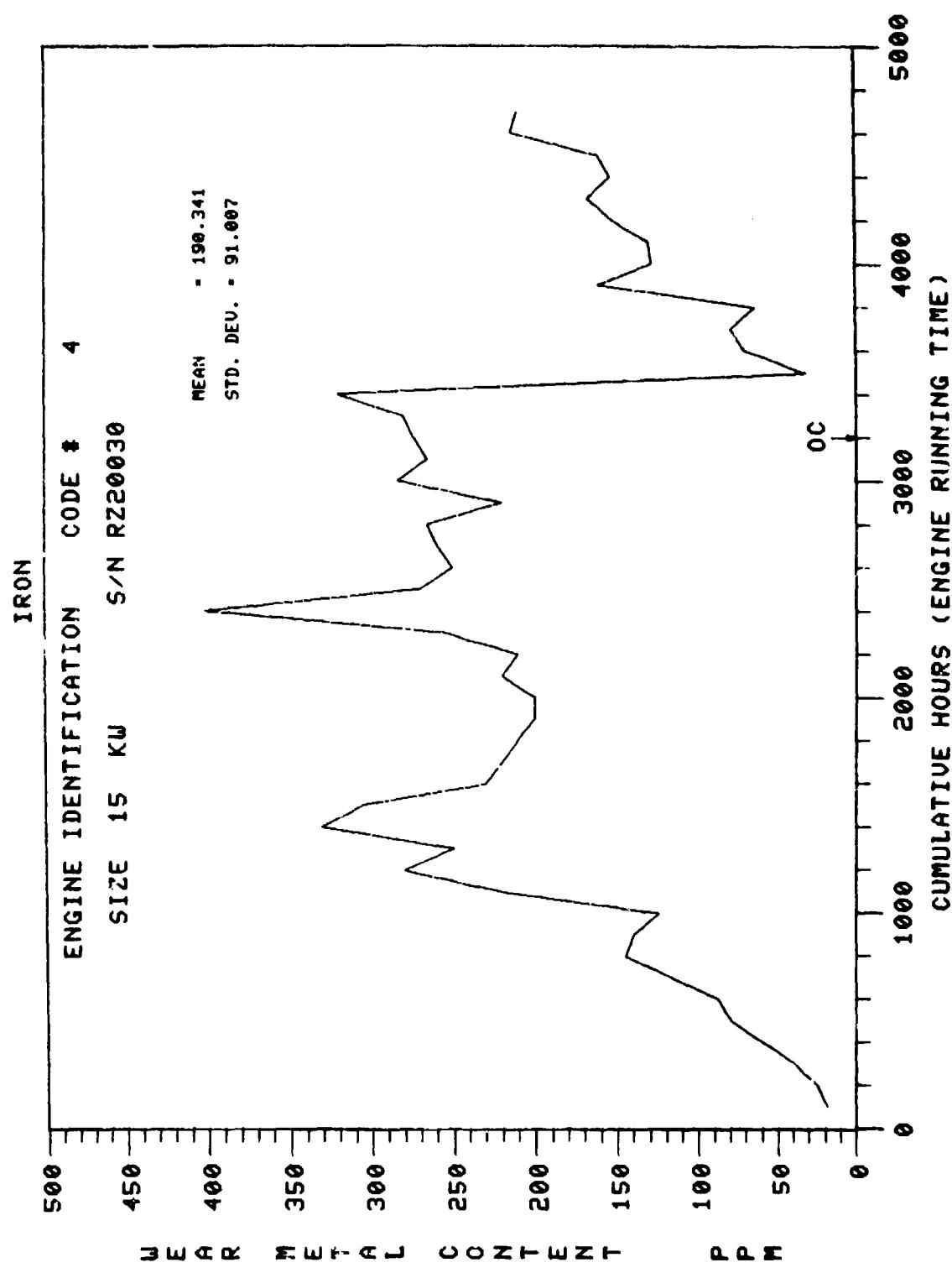


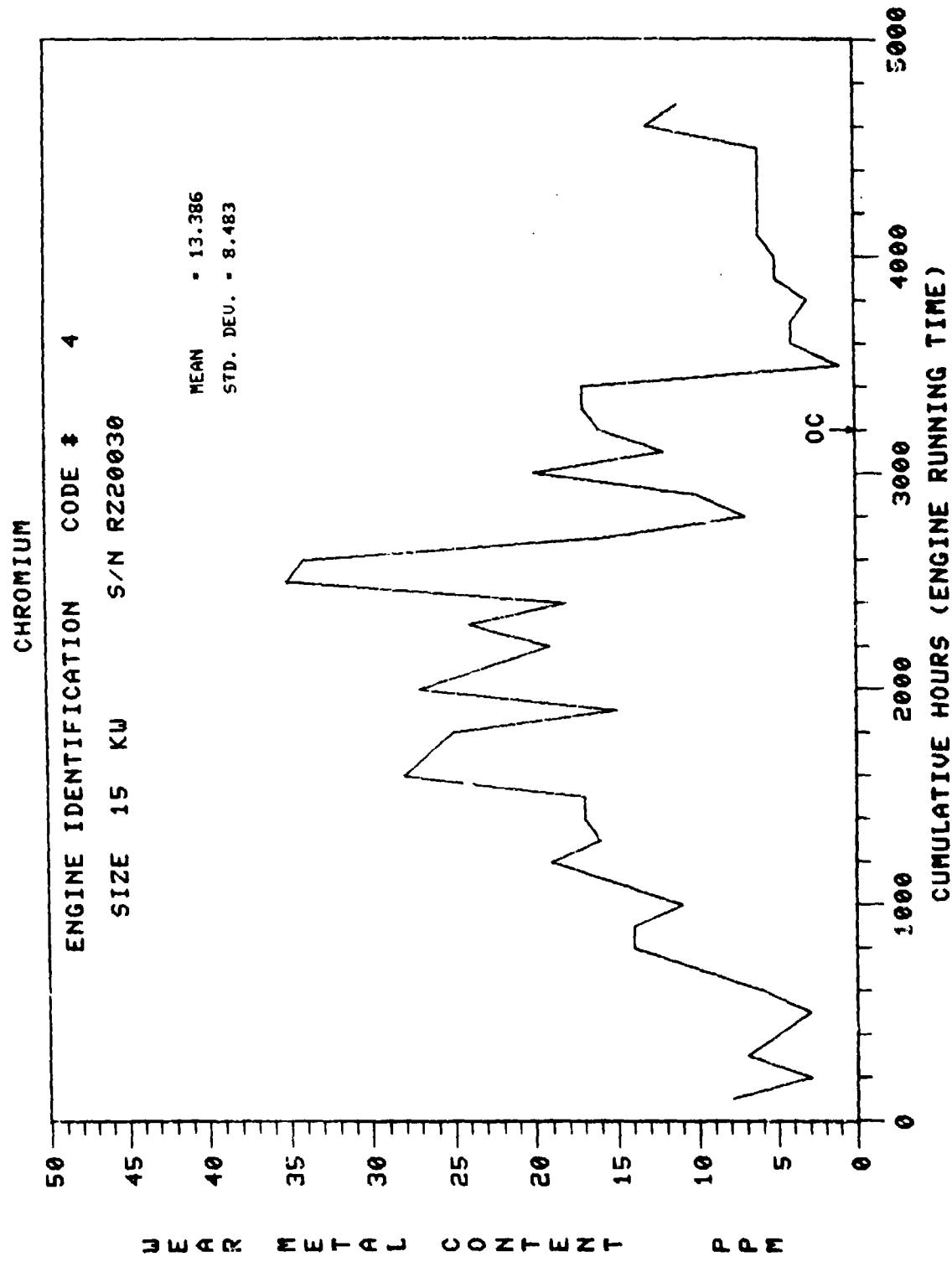




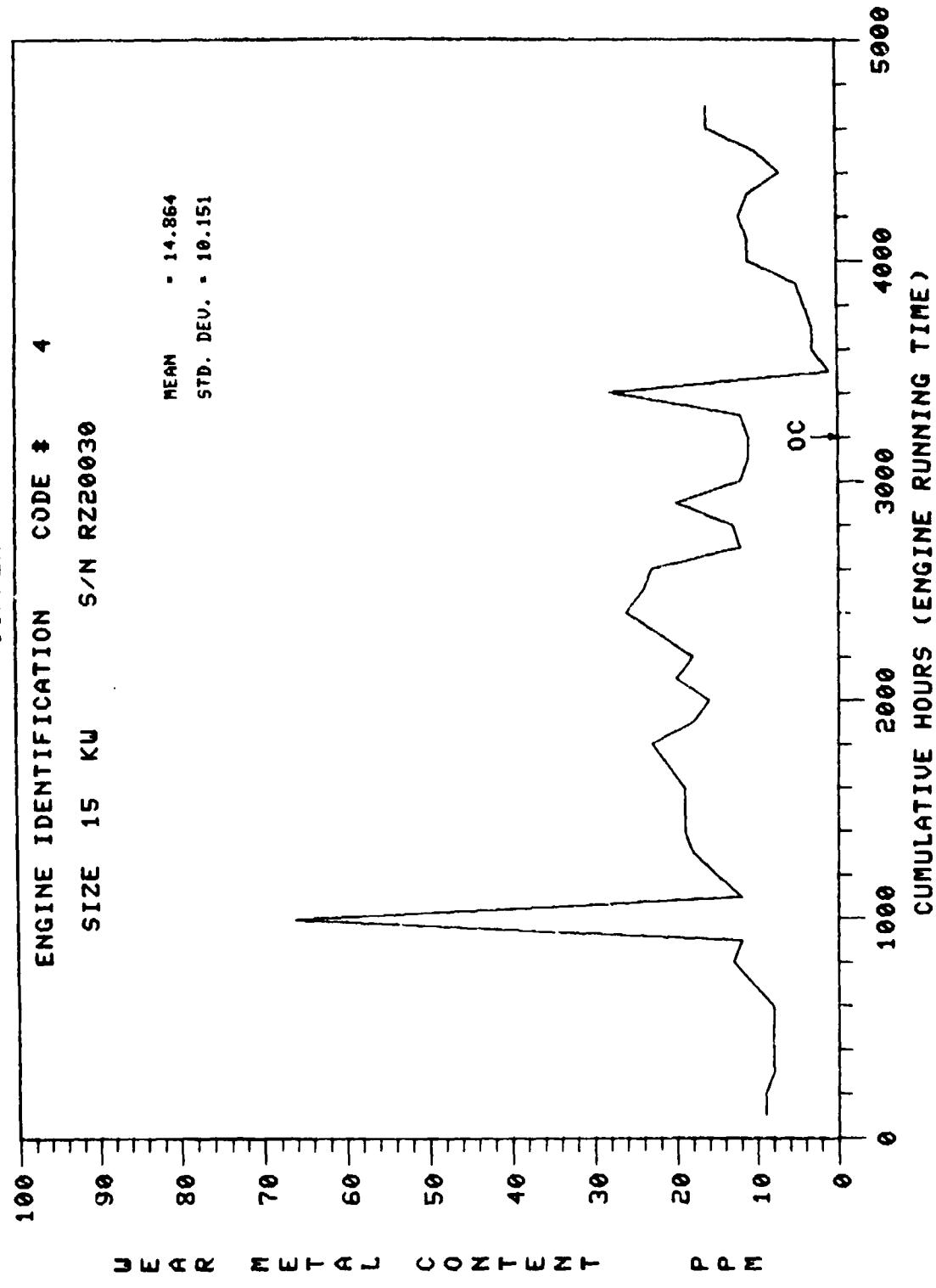


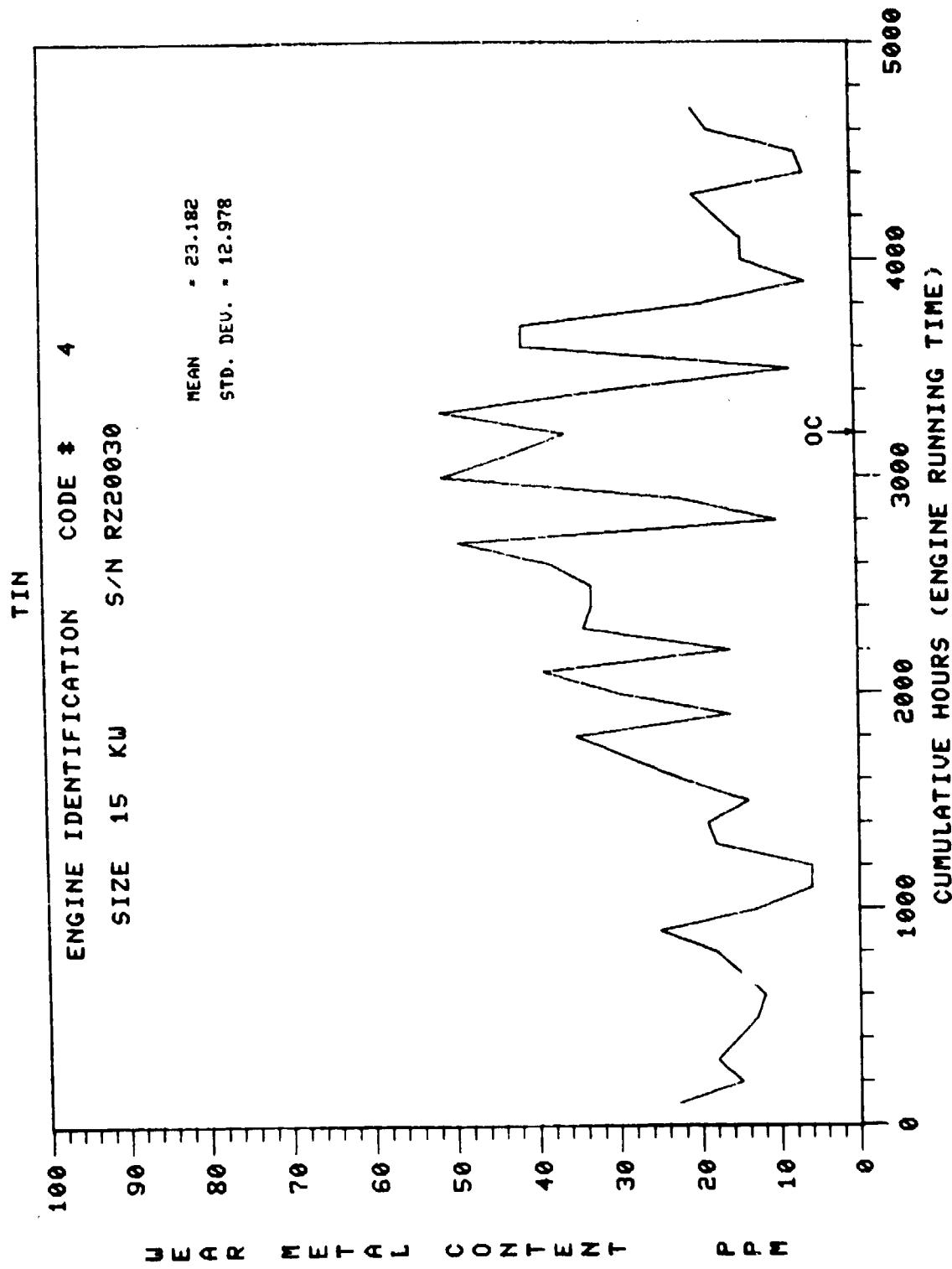


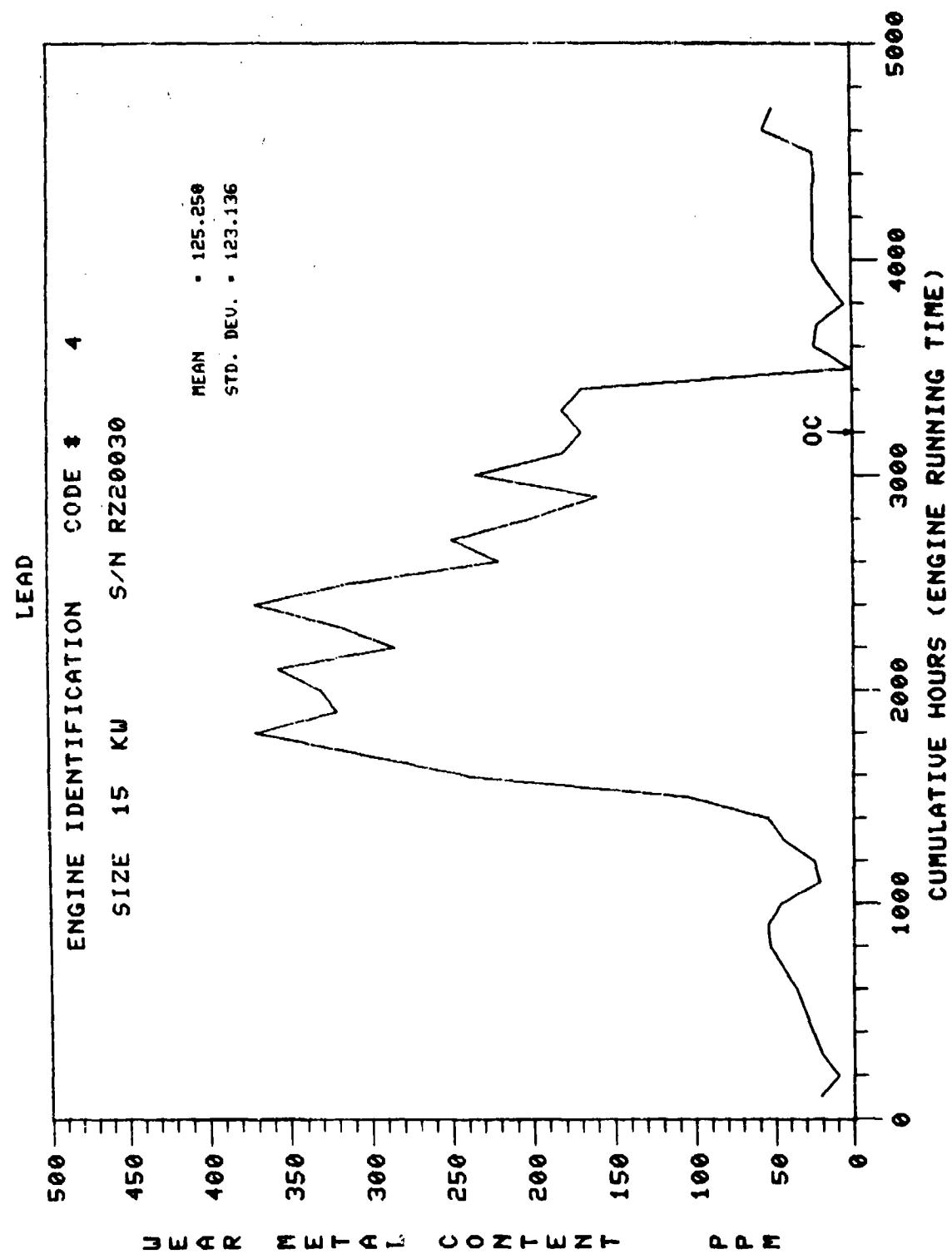


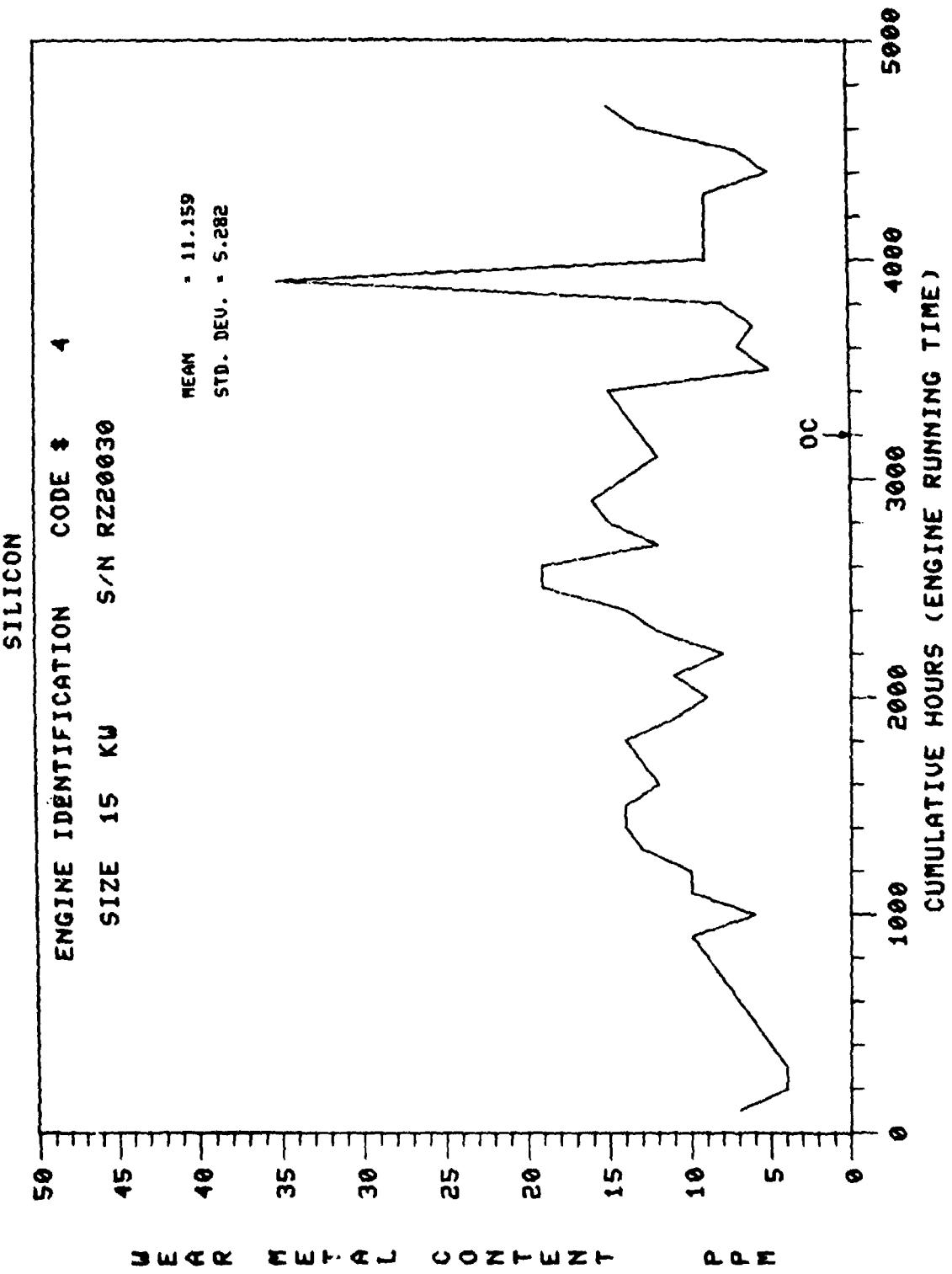


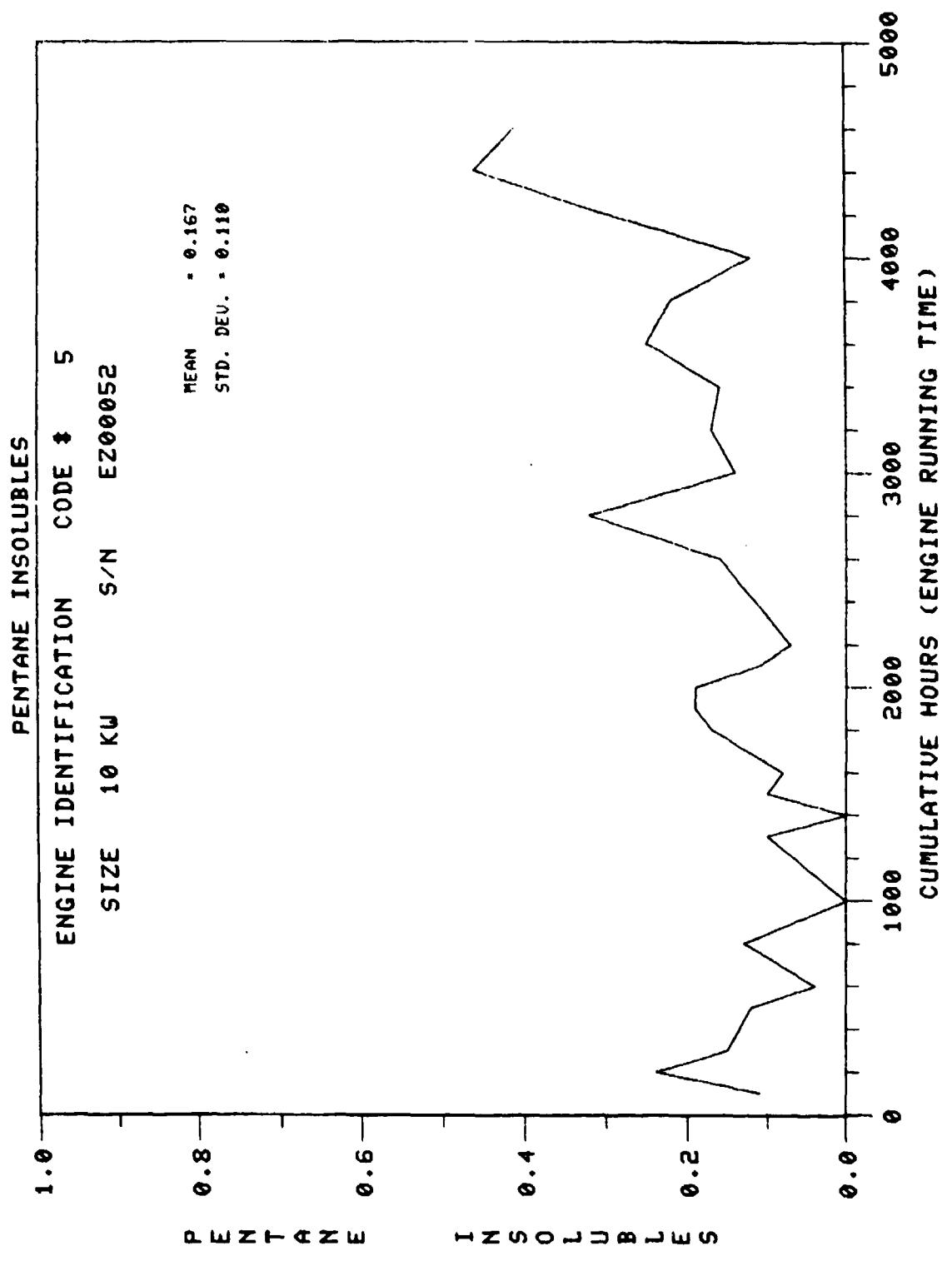
COPPER

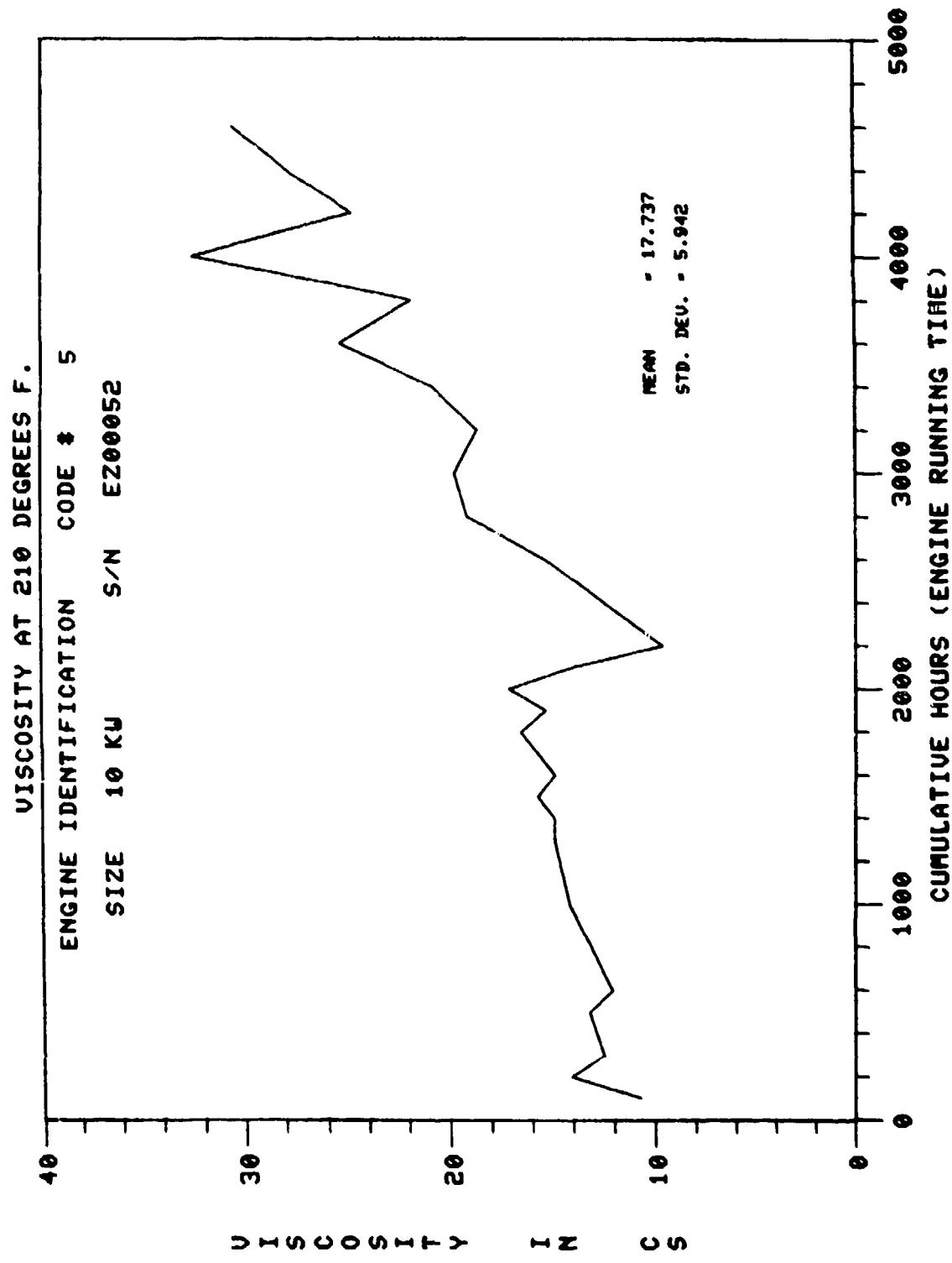


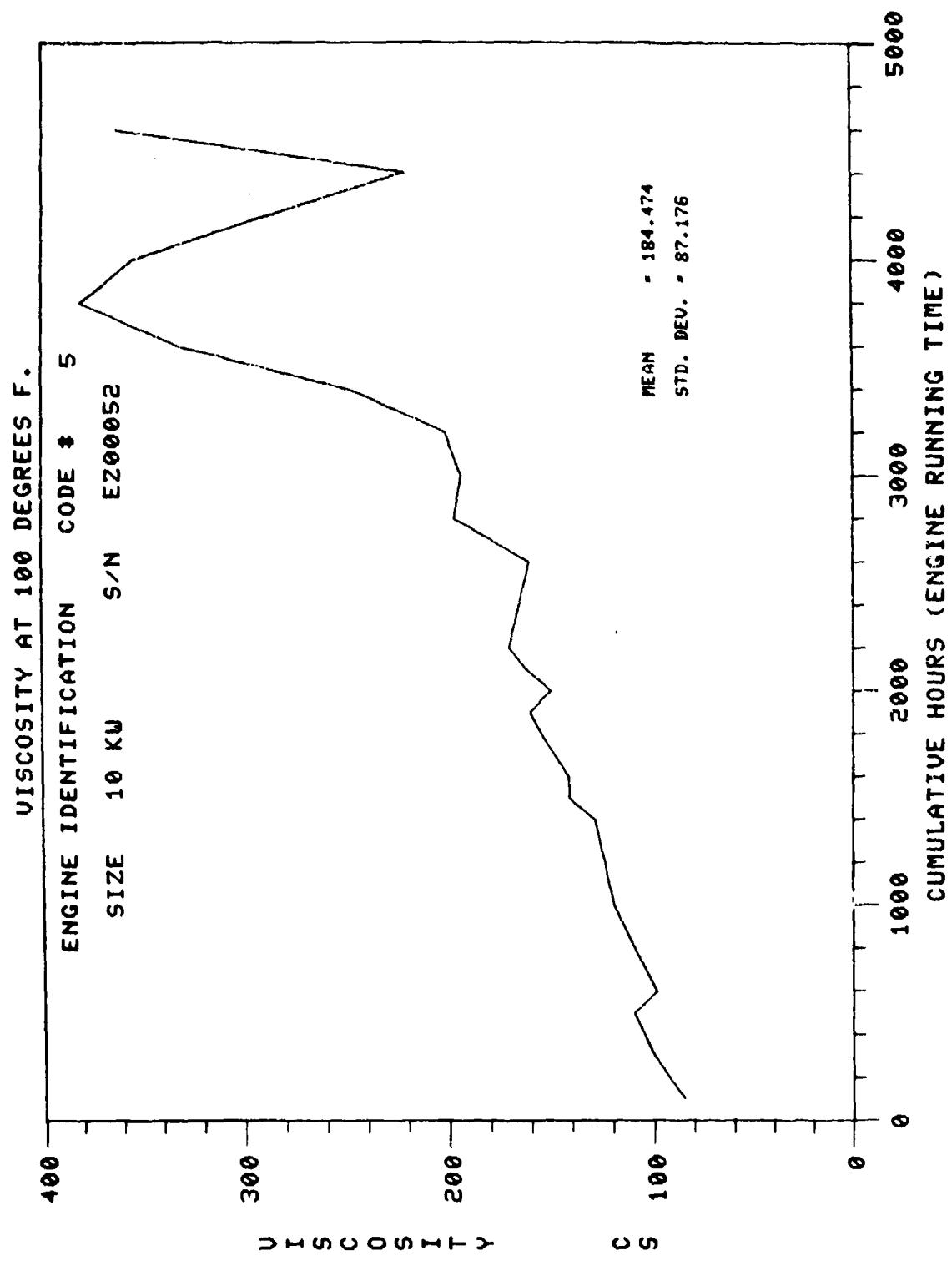


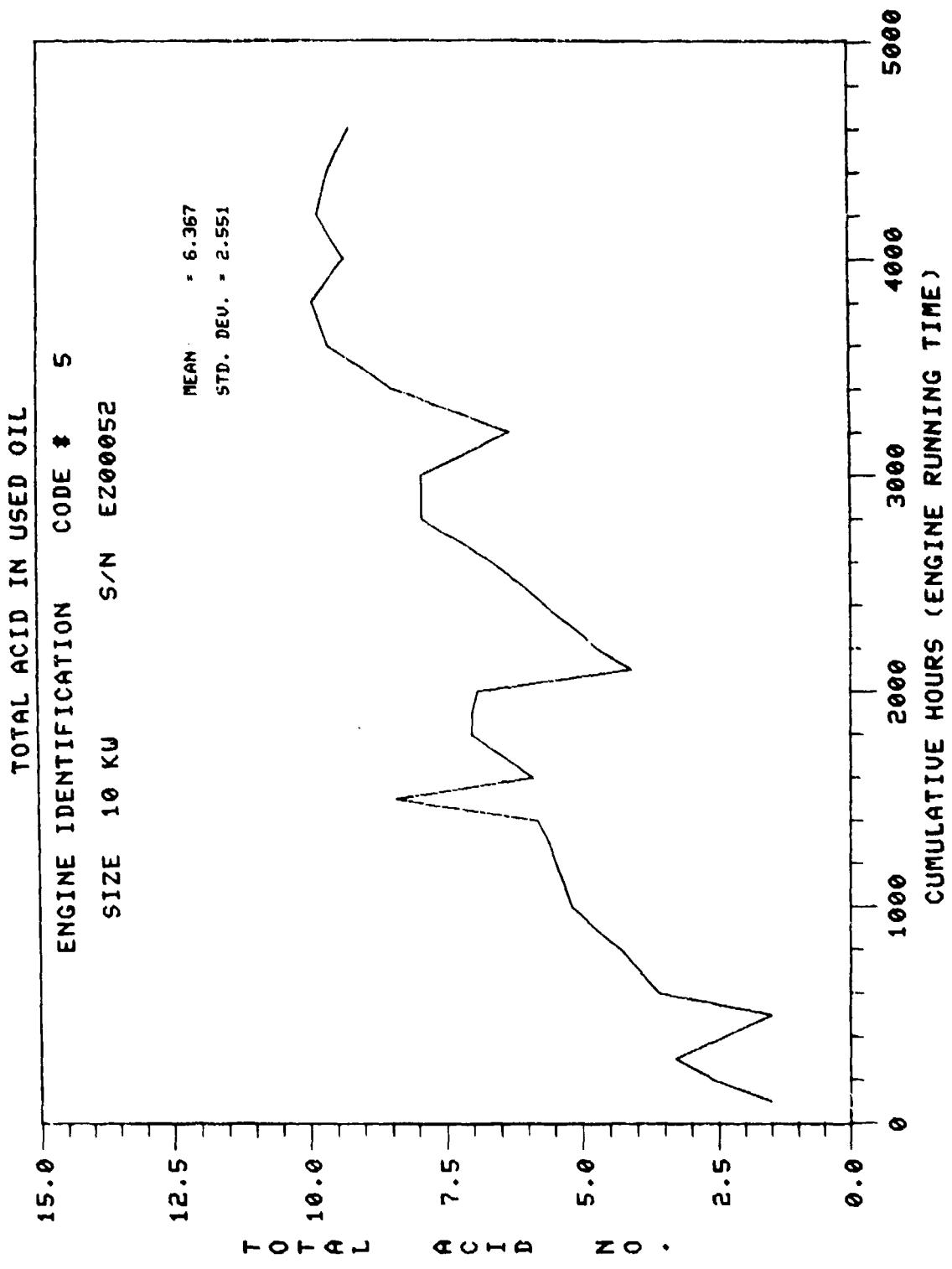


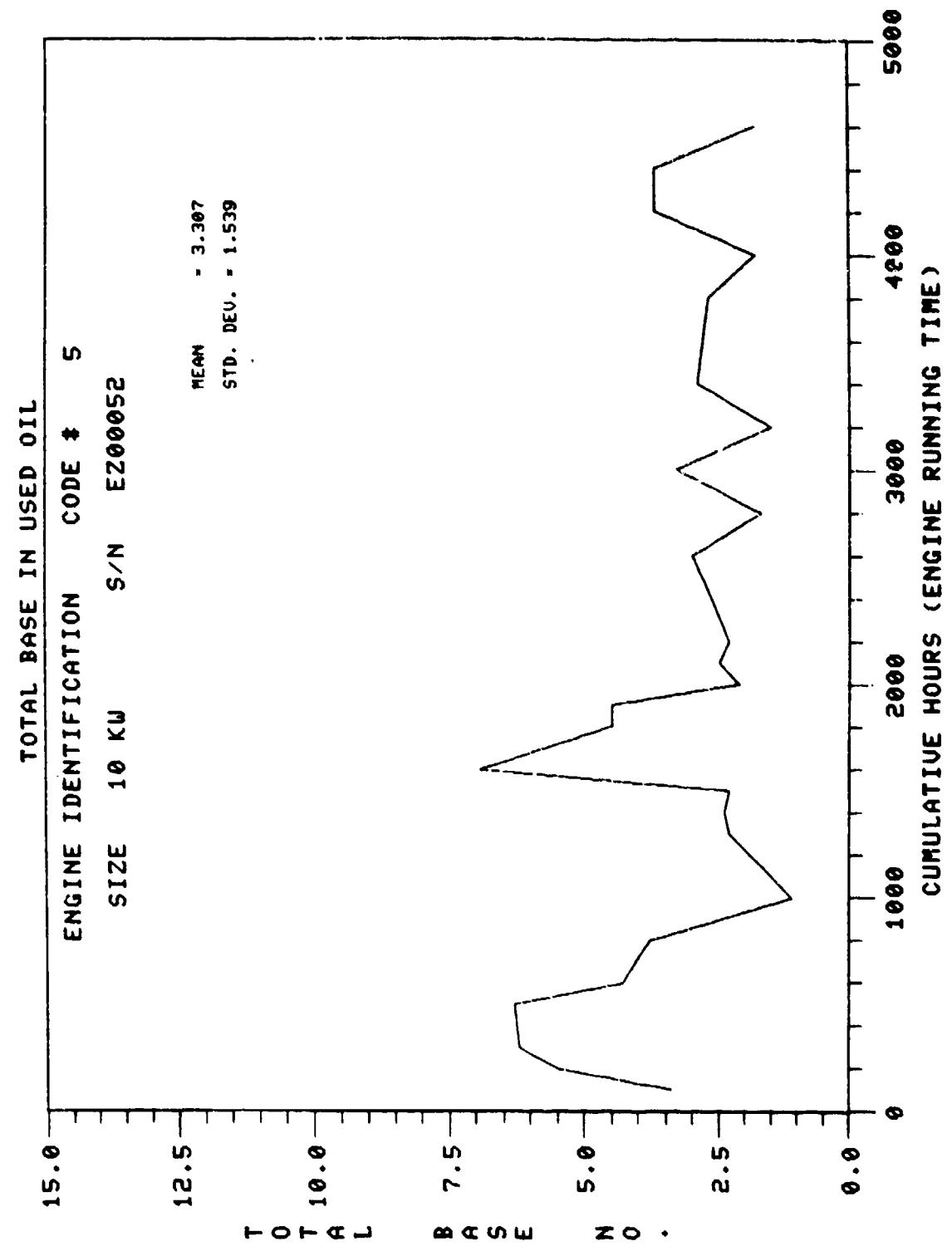


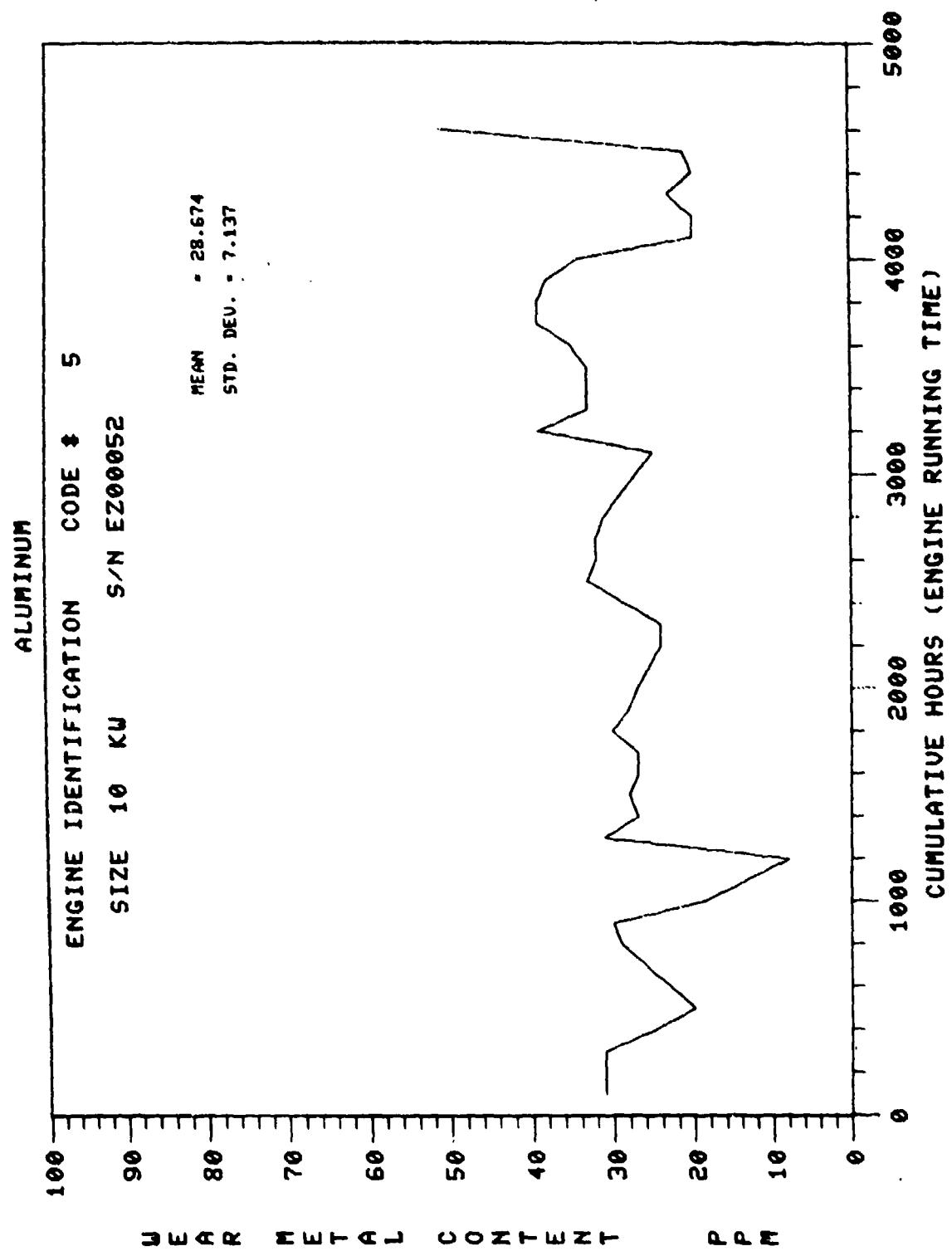


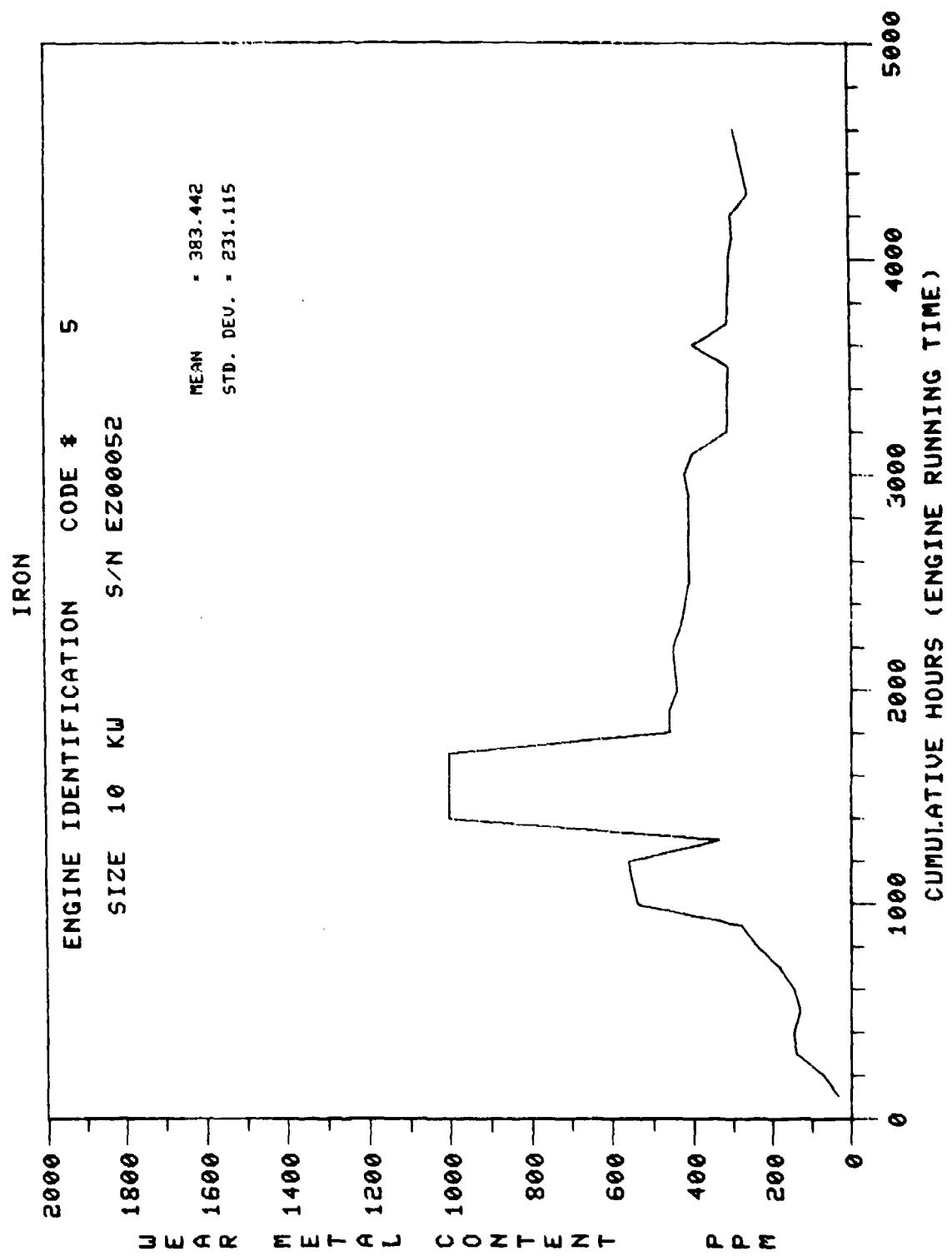


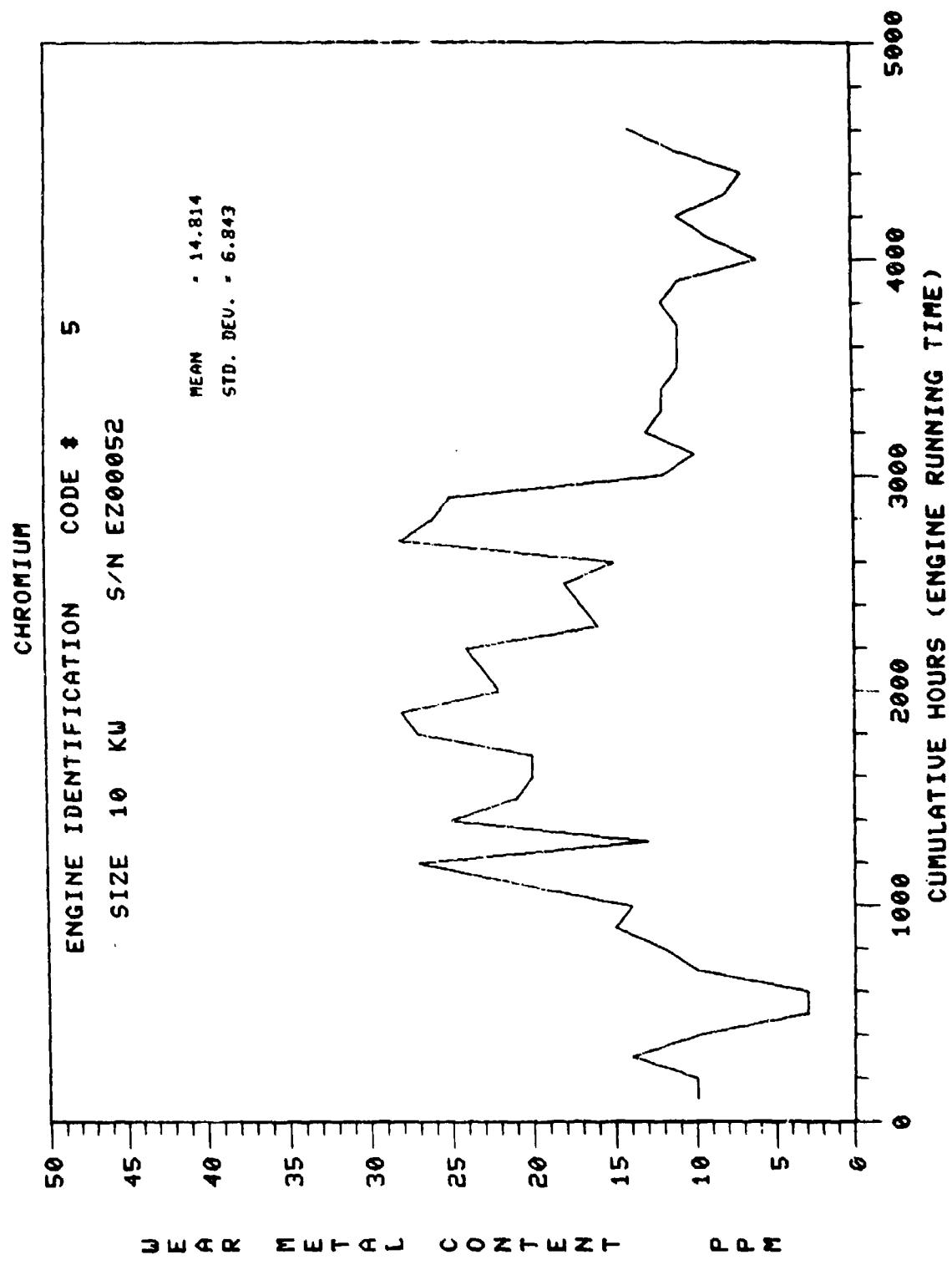


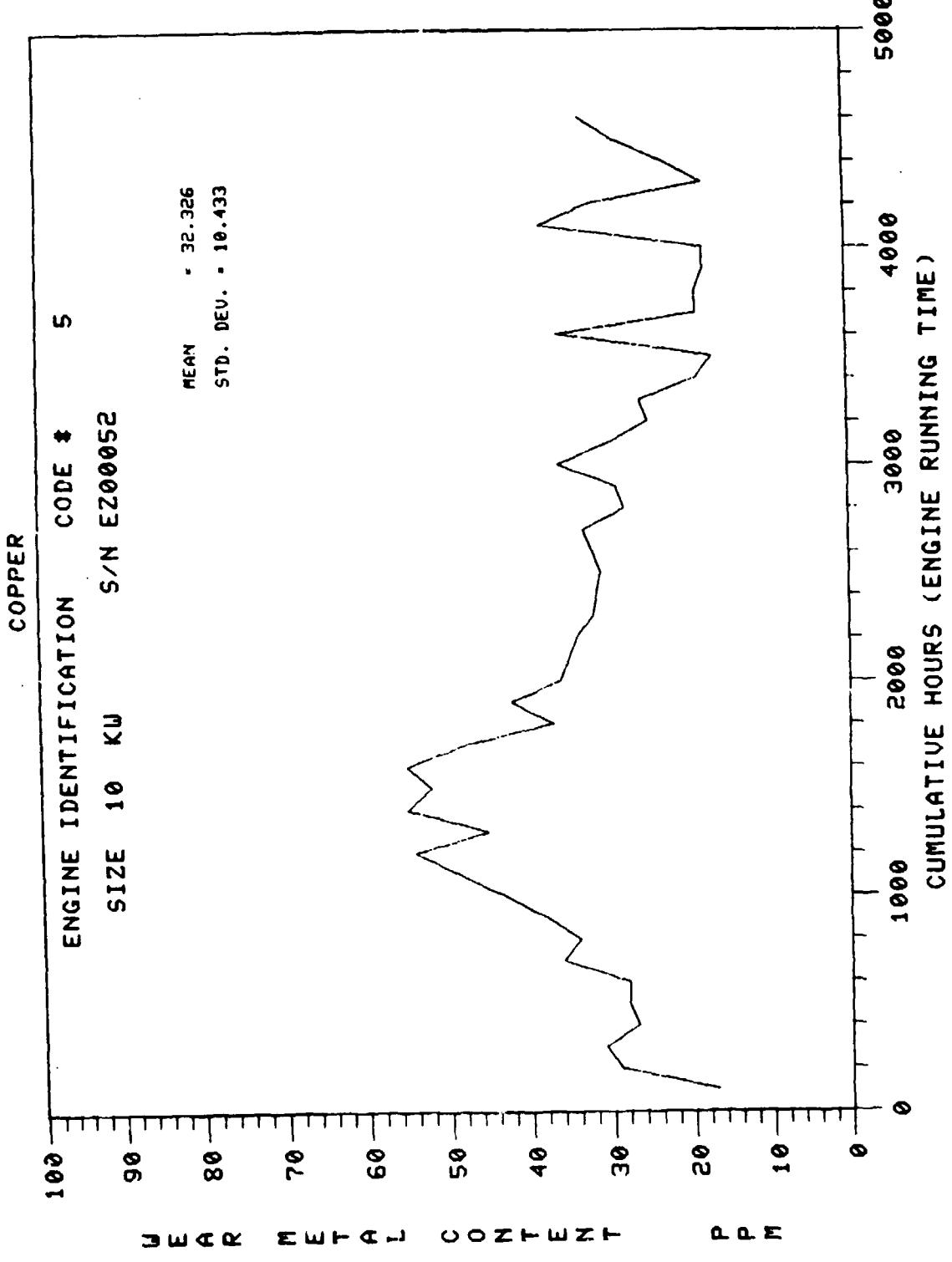


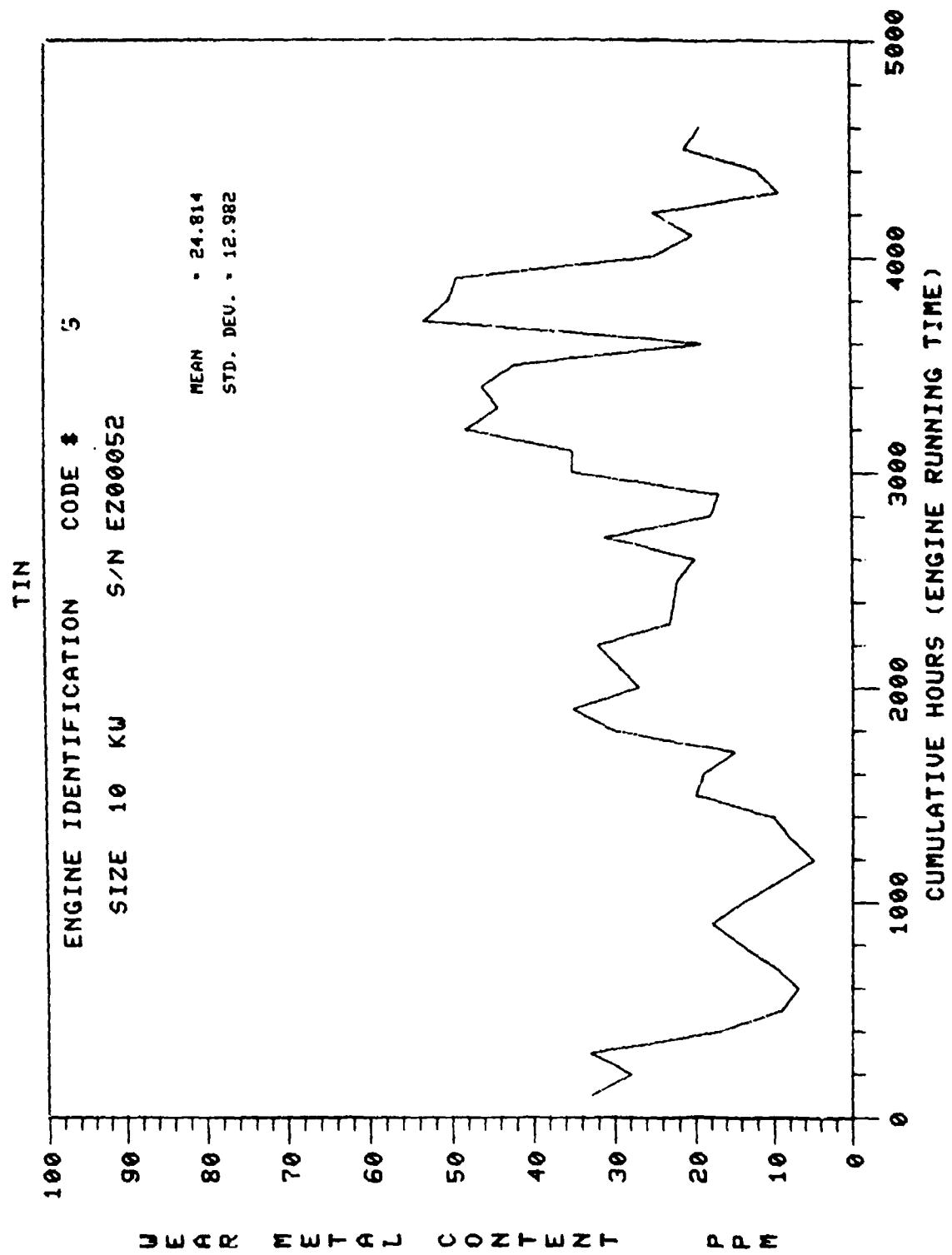


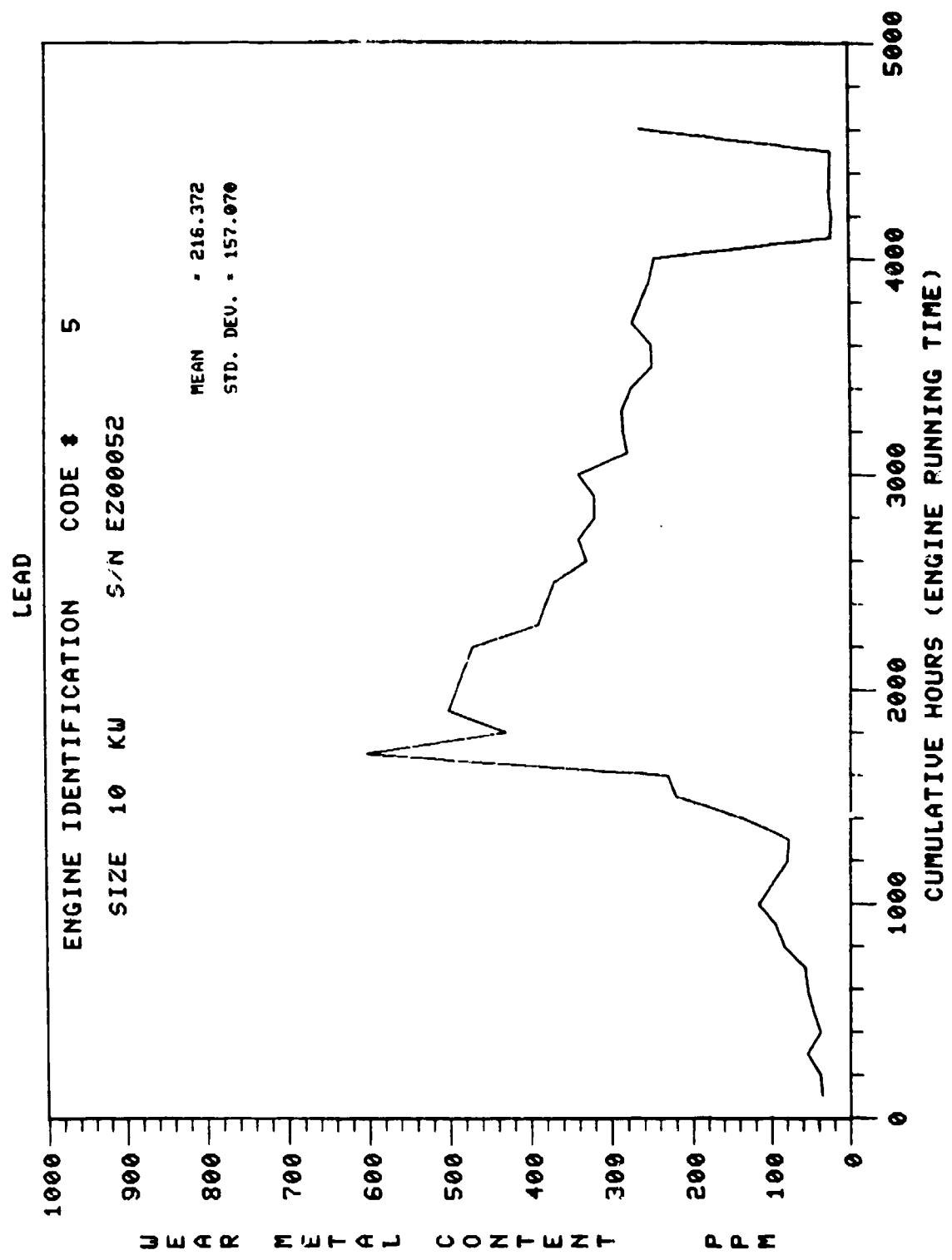


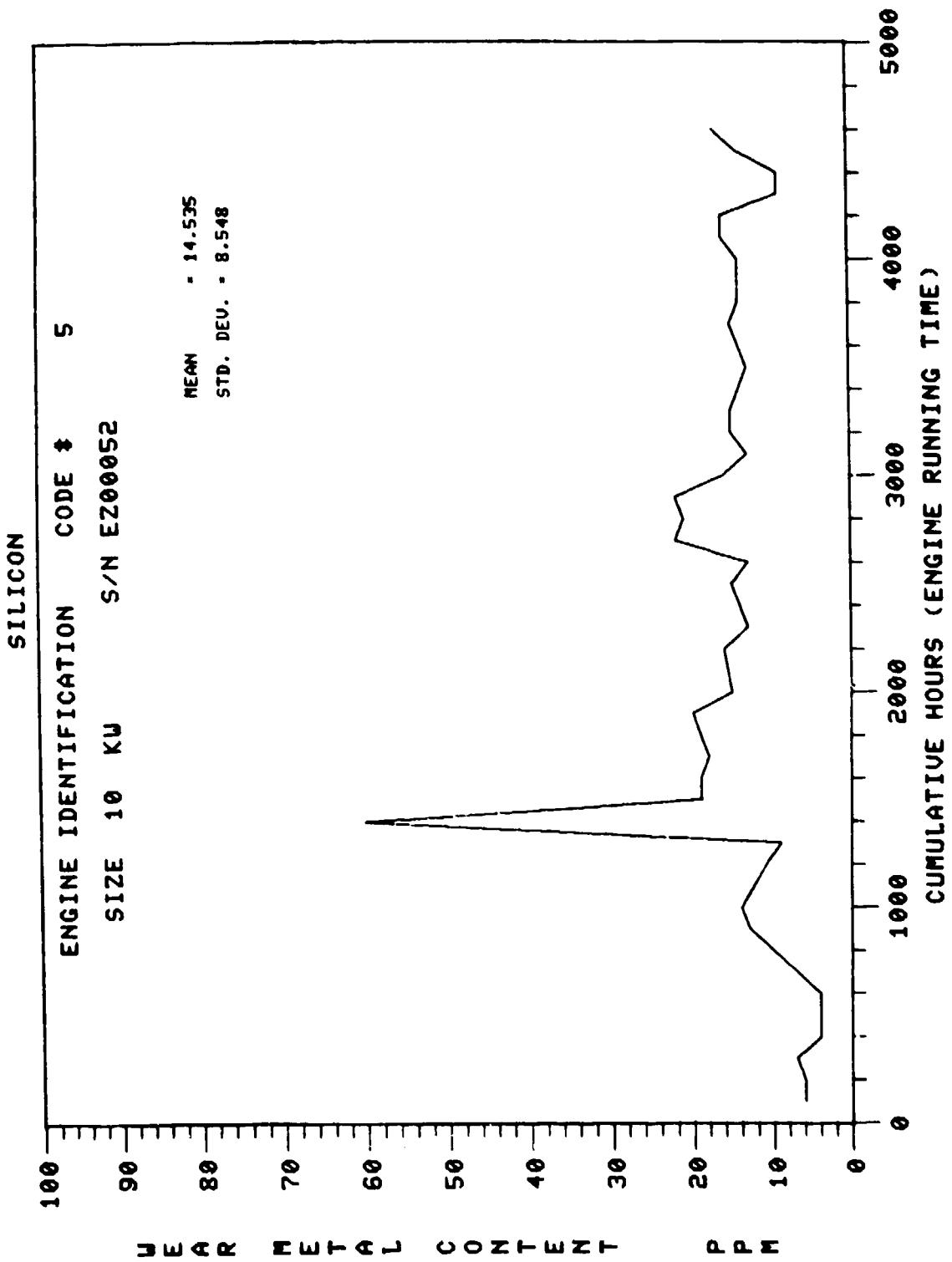


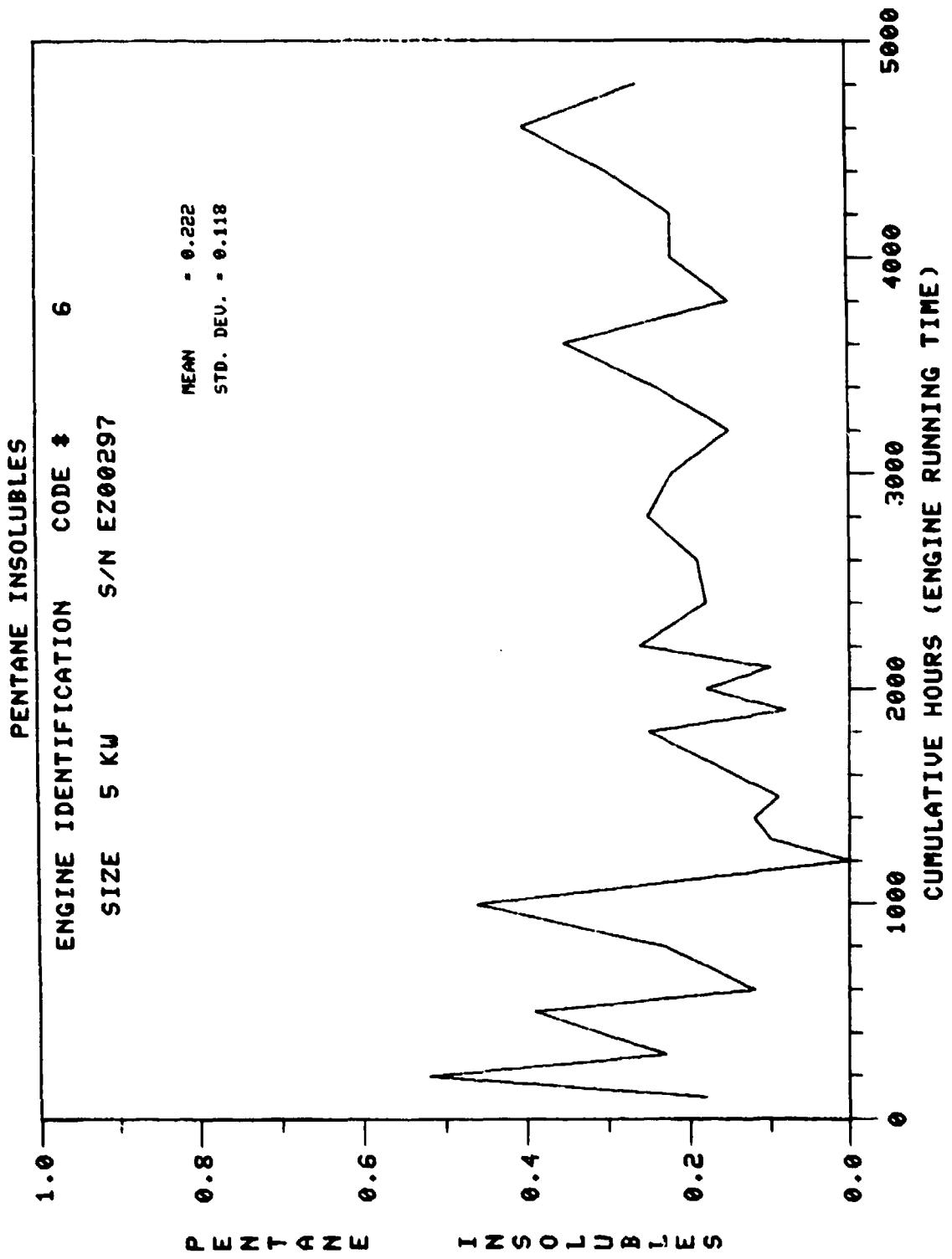


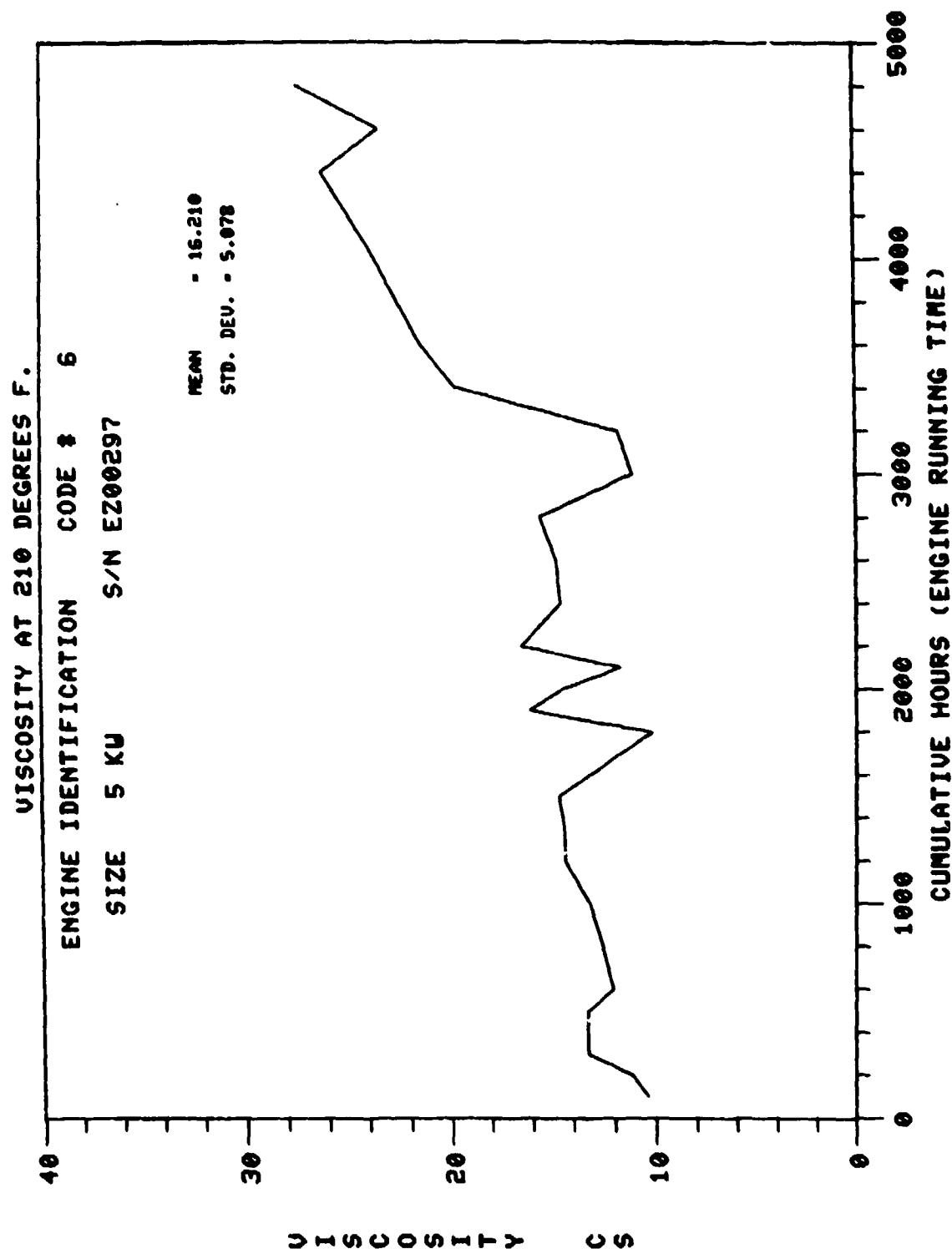


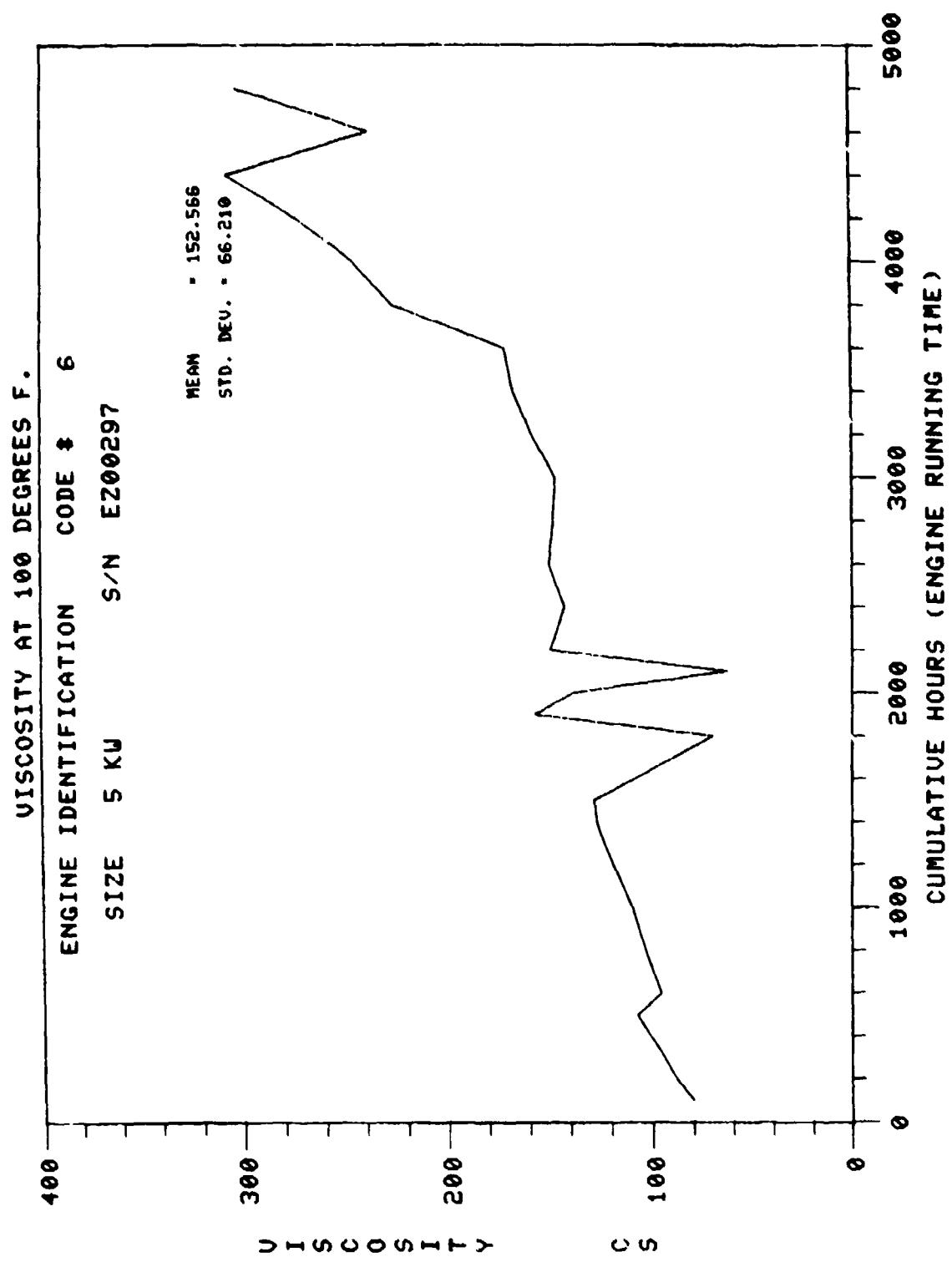


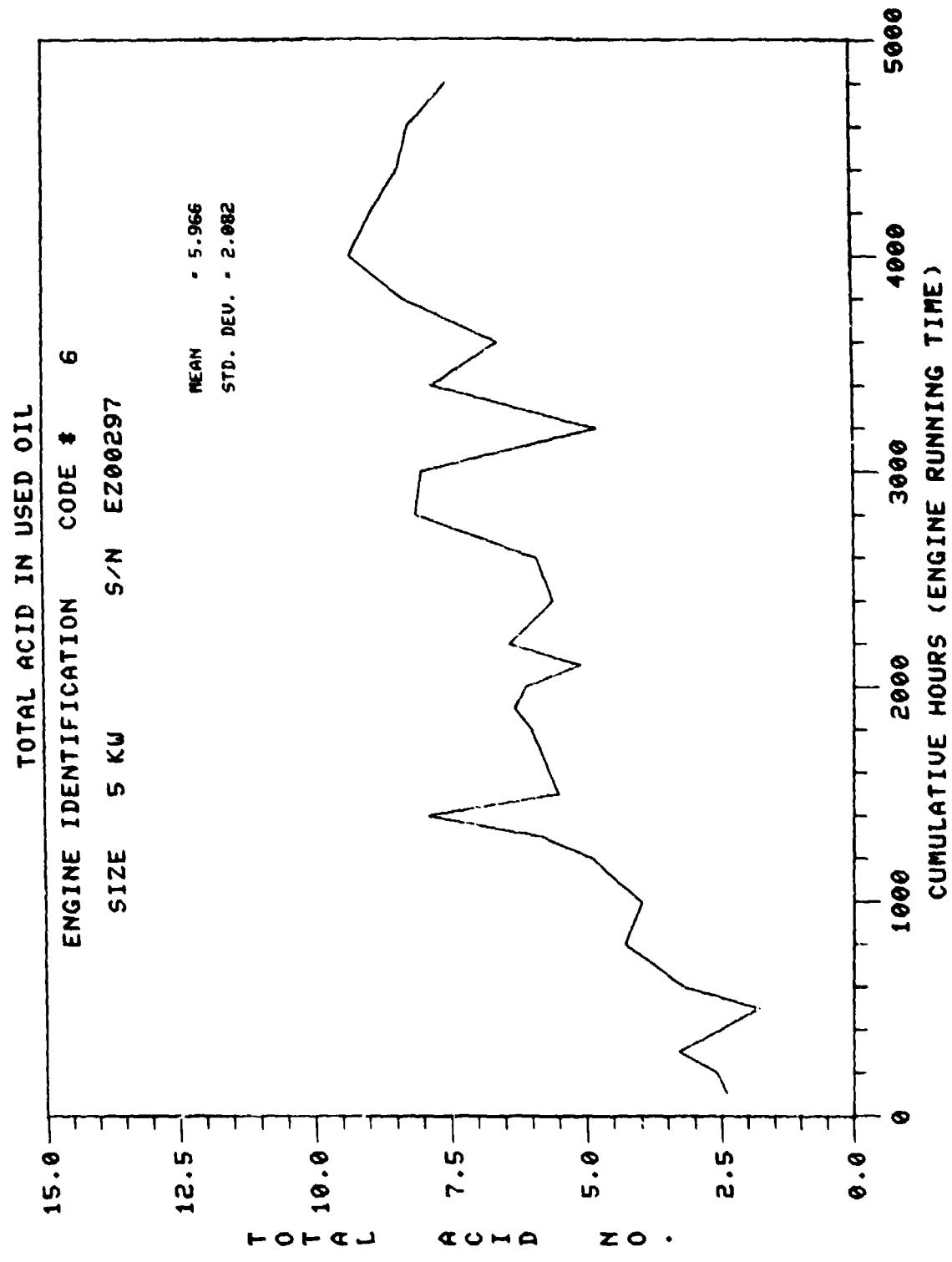


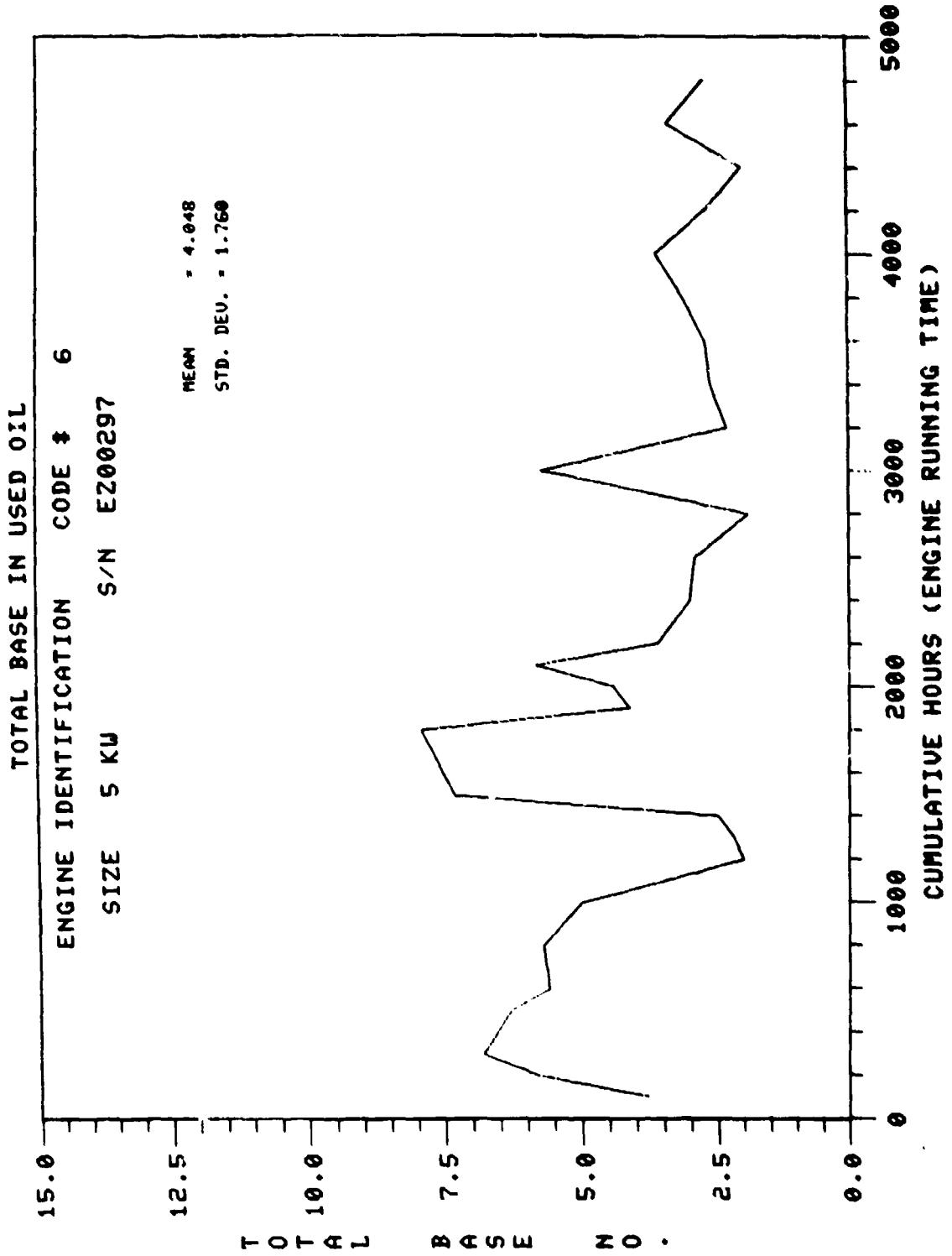


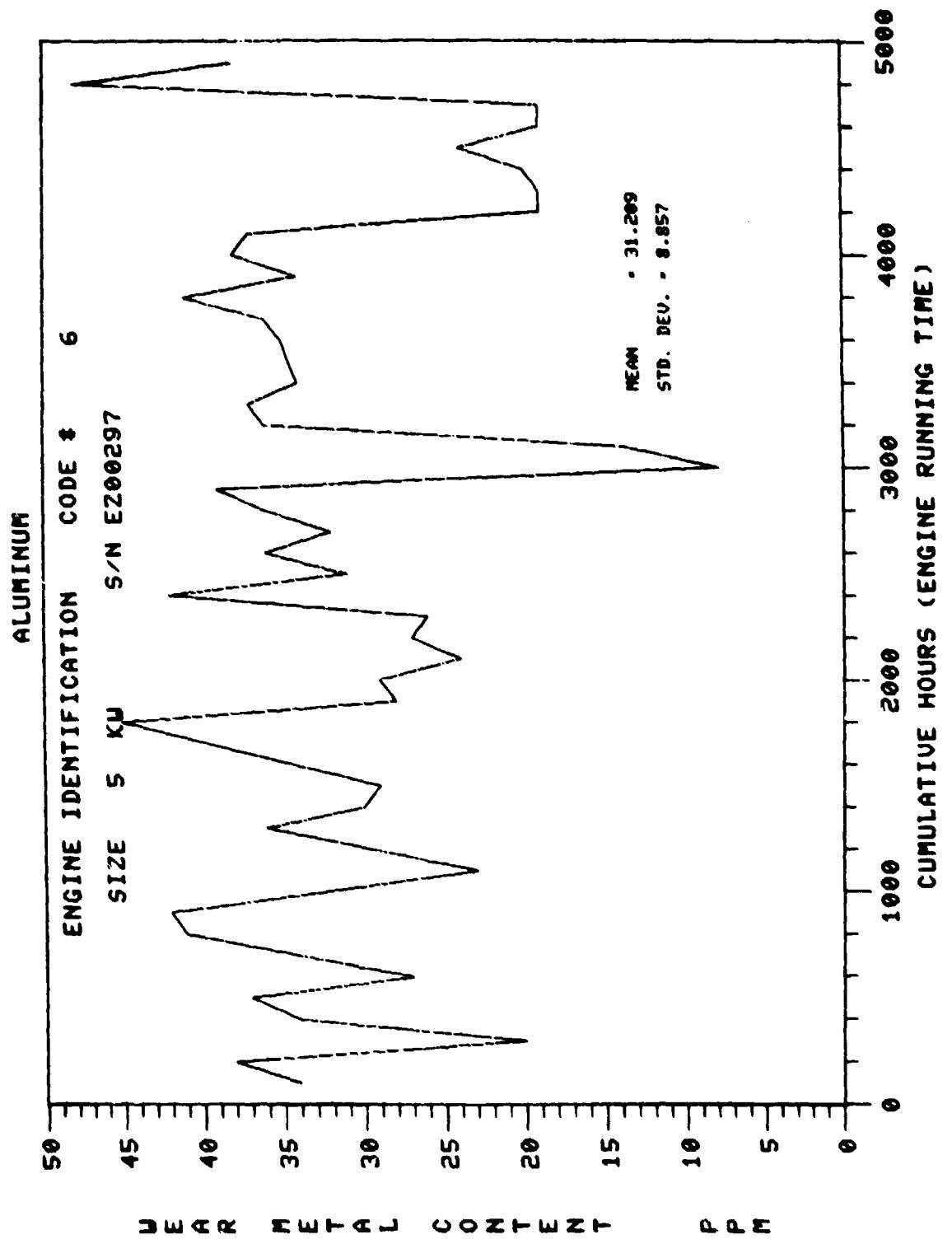


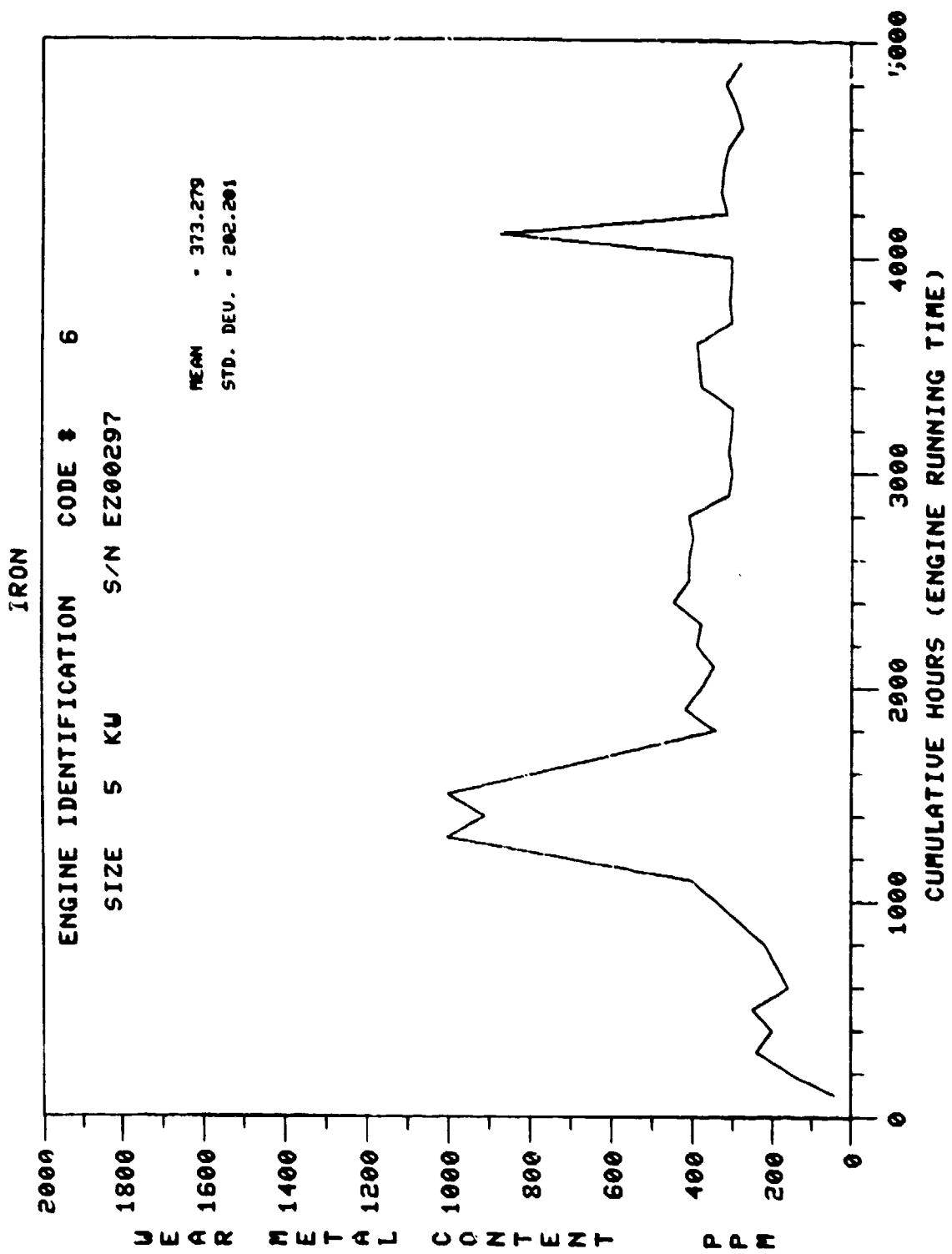




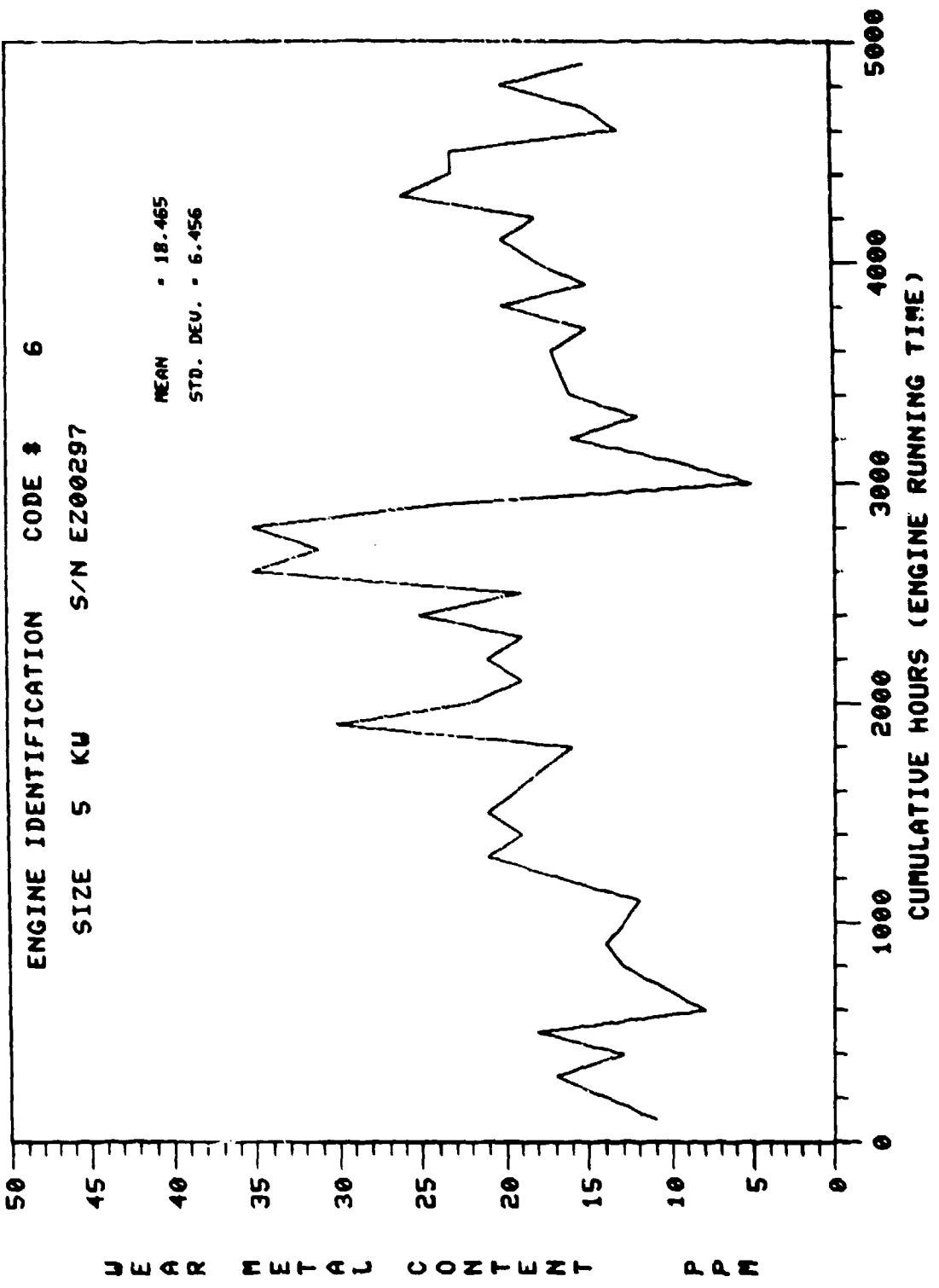




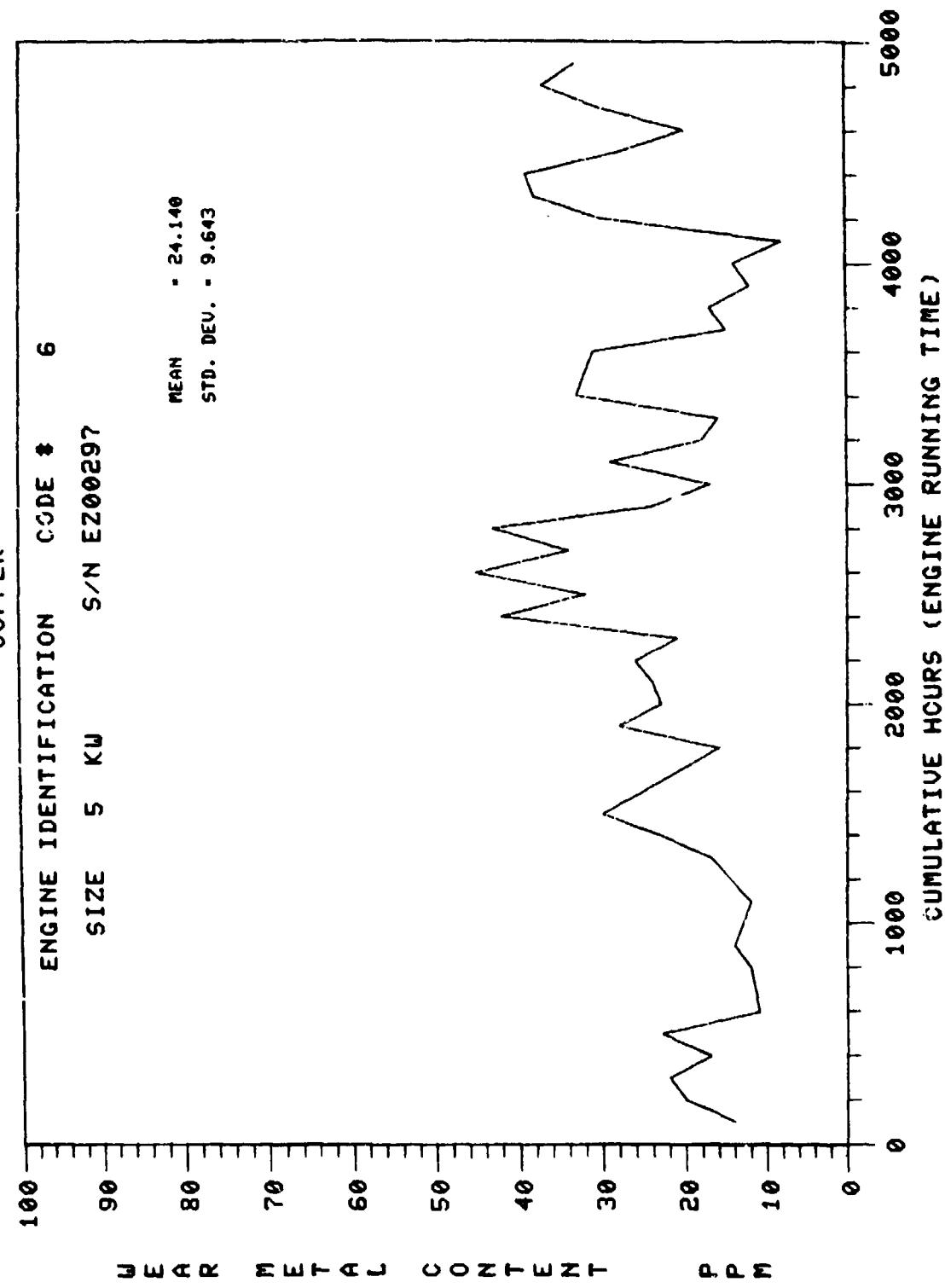


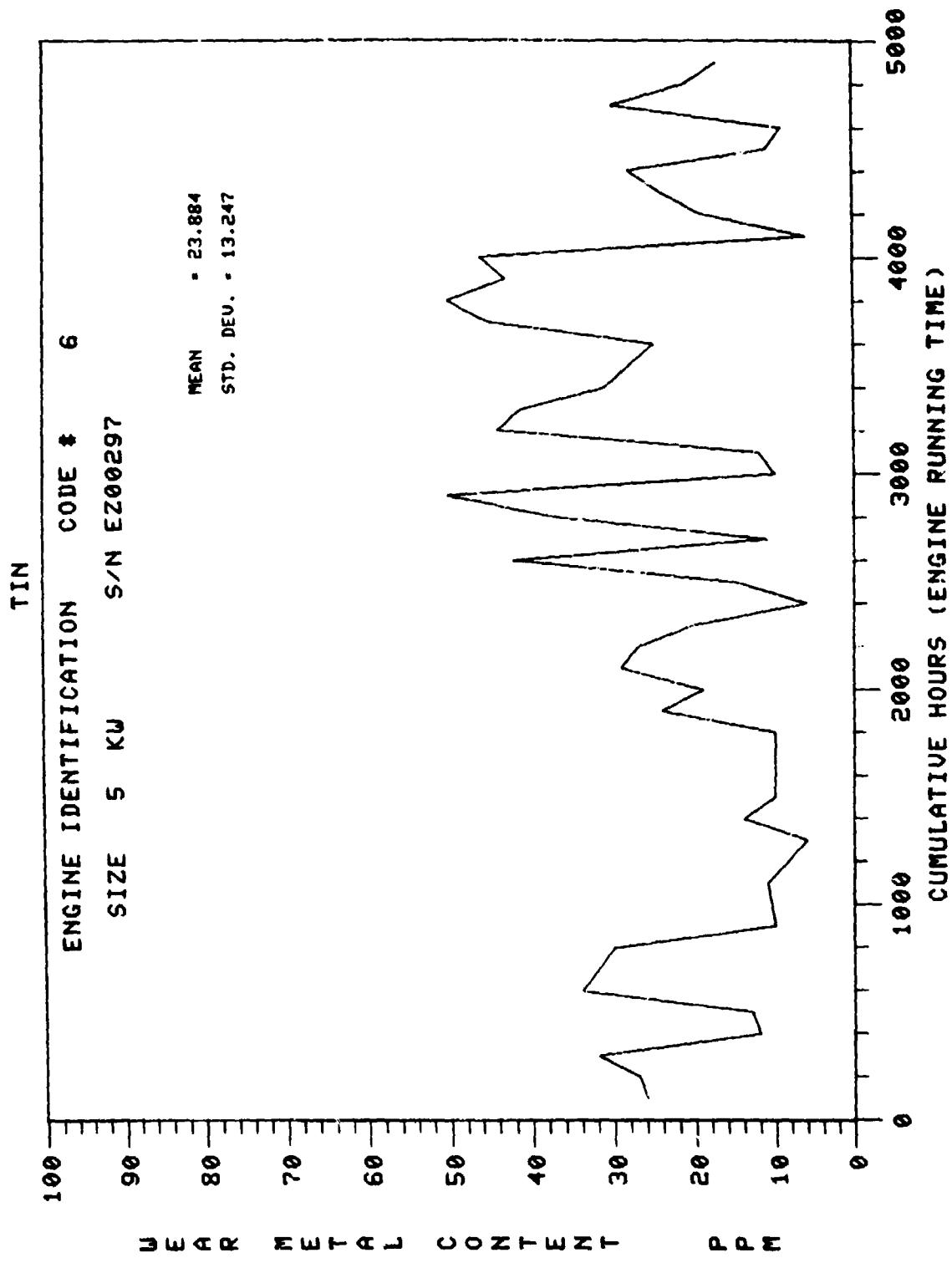


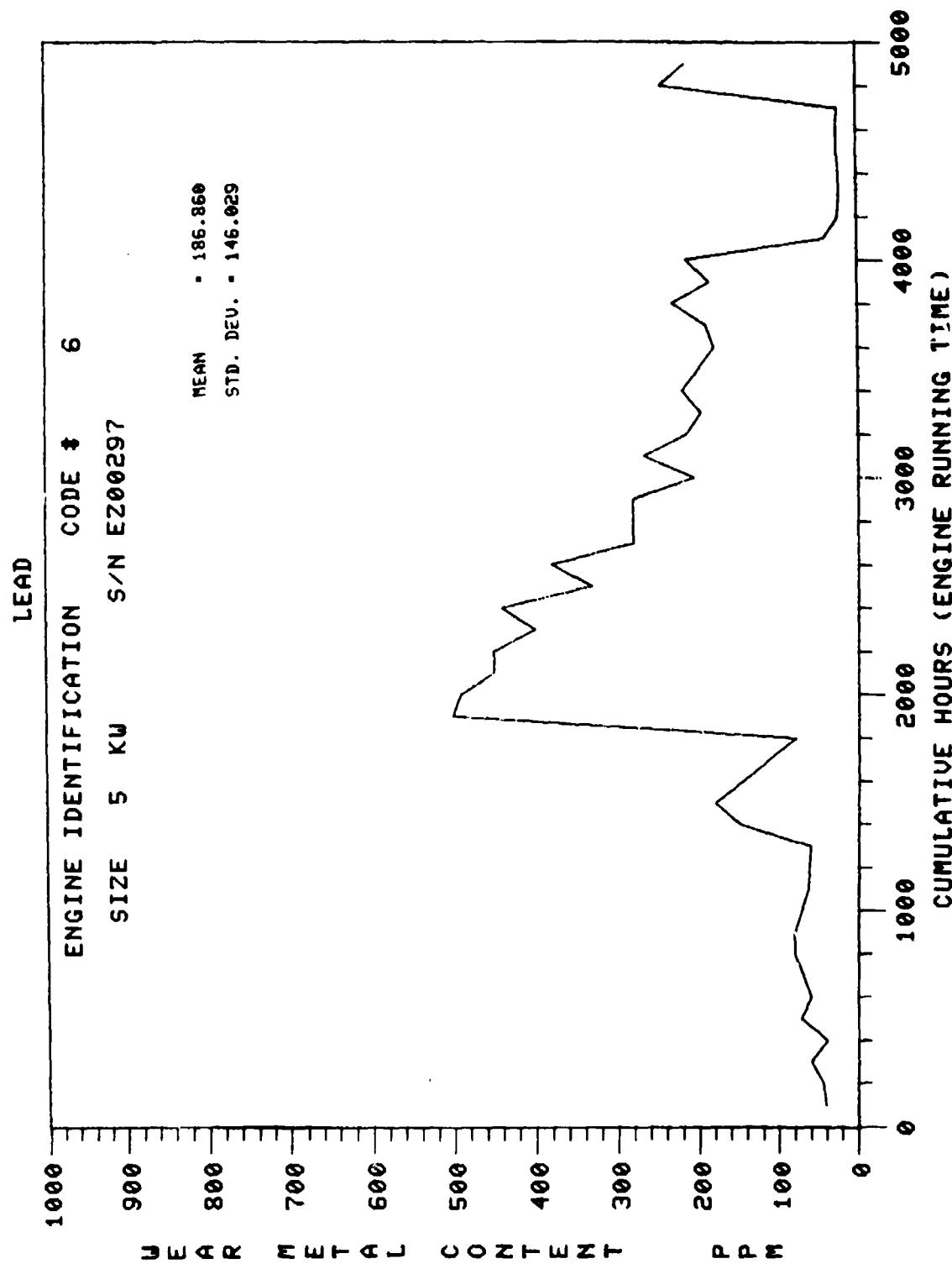
CHROMIUM

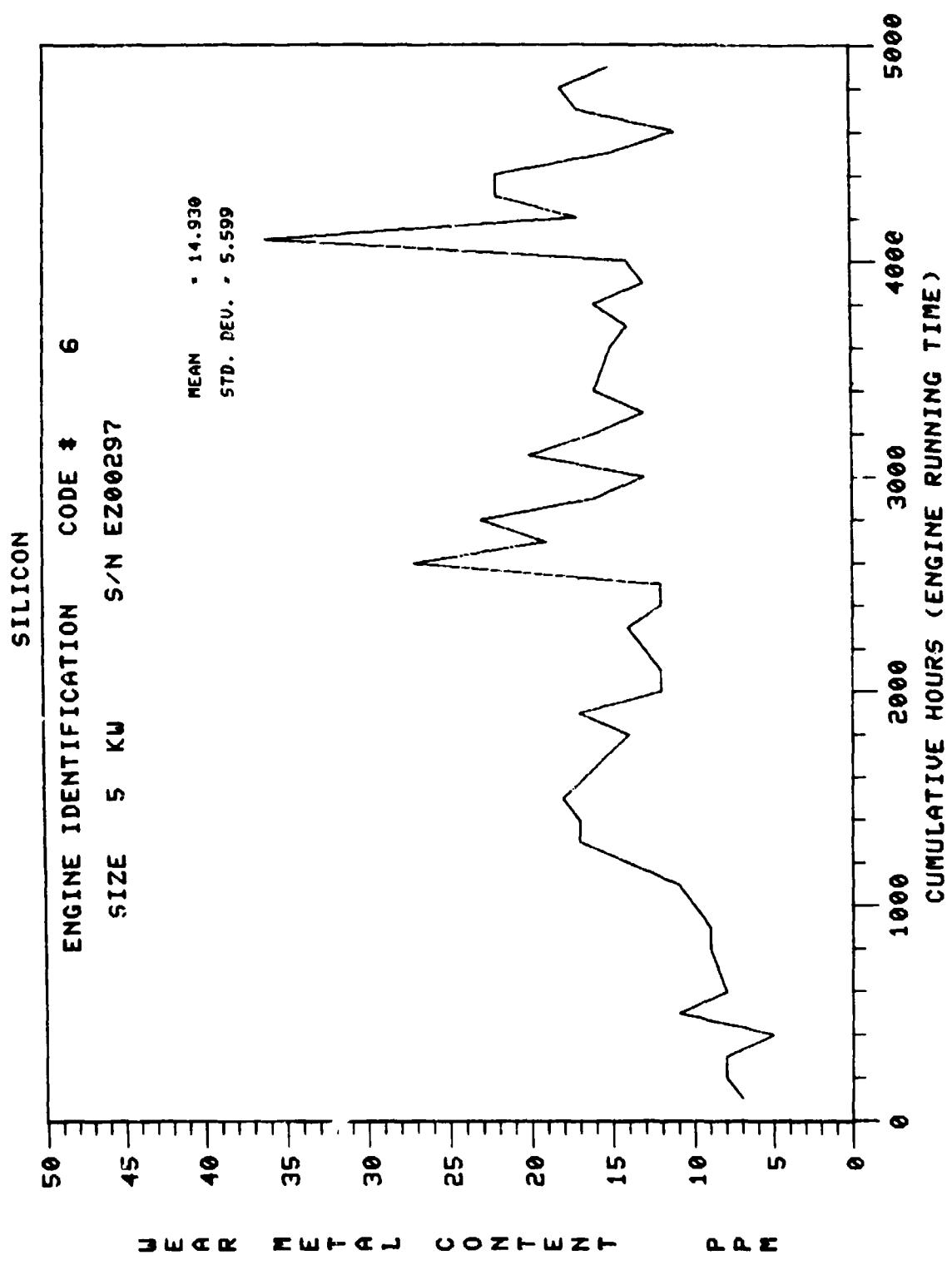


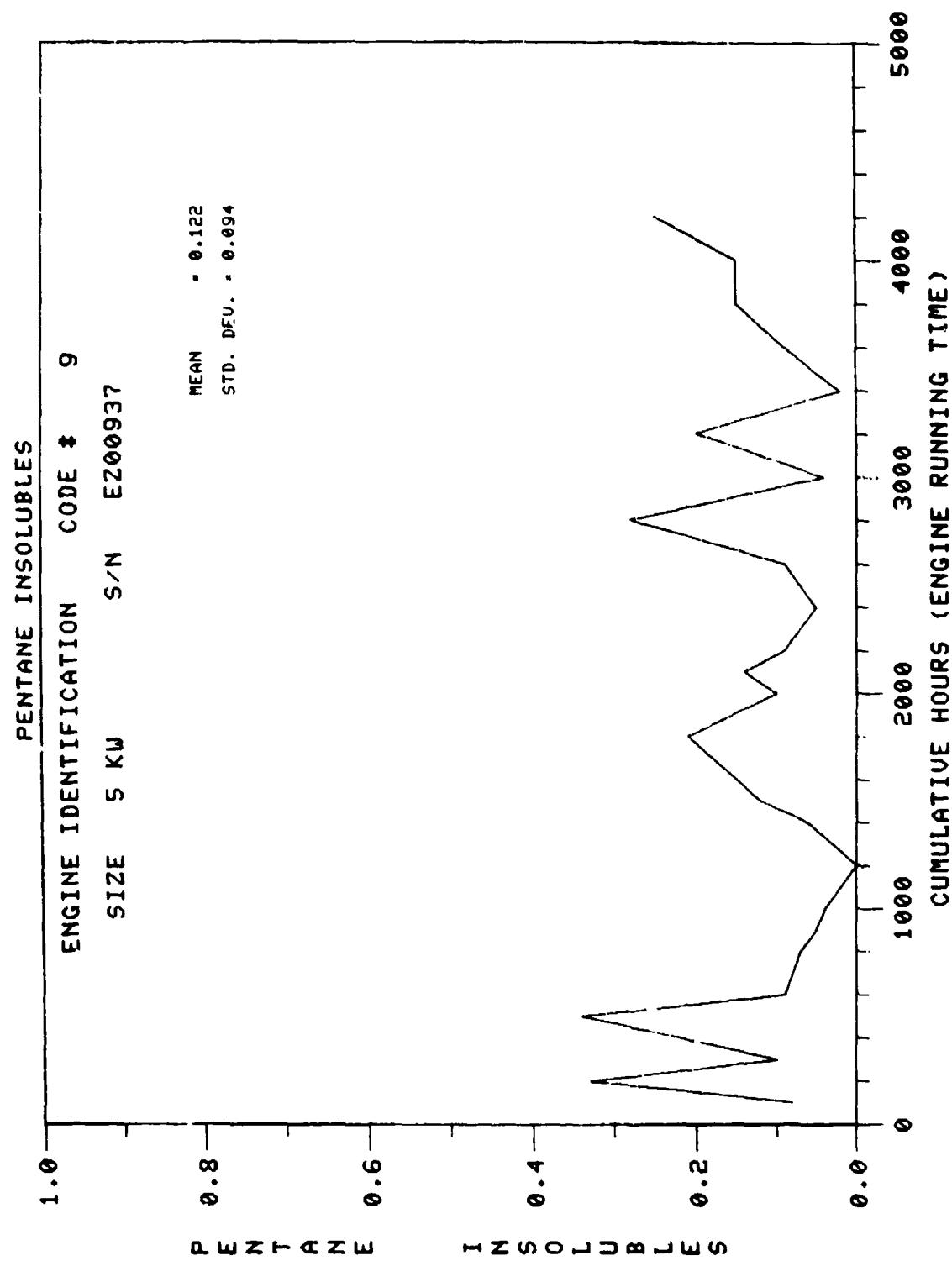
COPPER

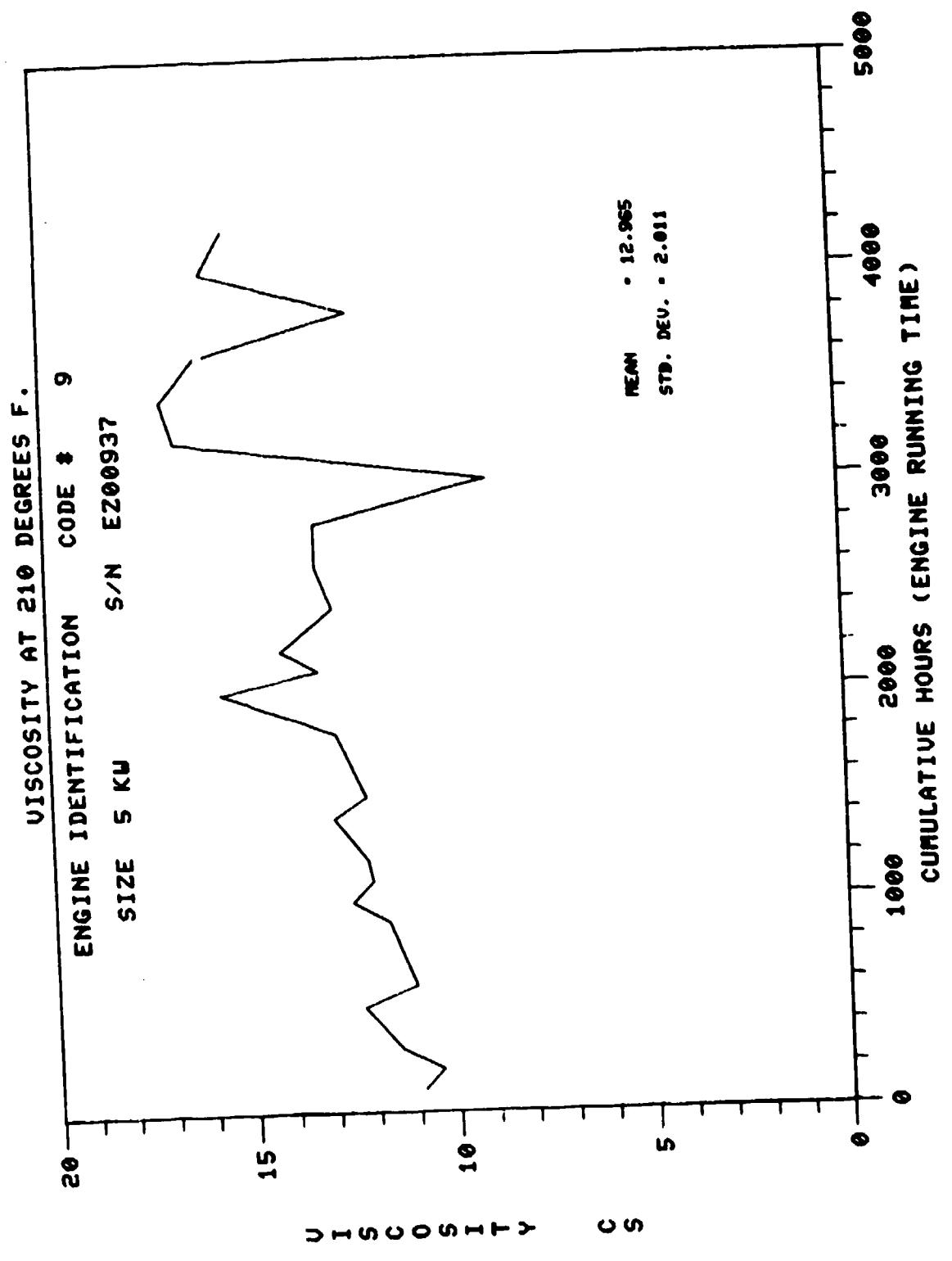


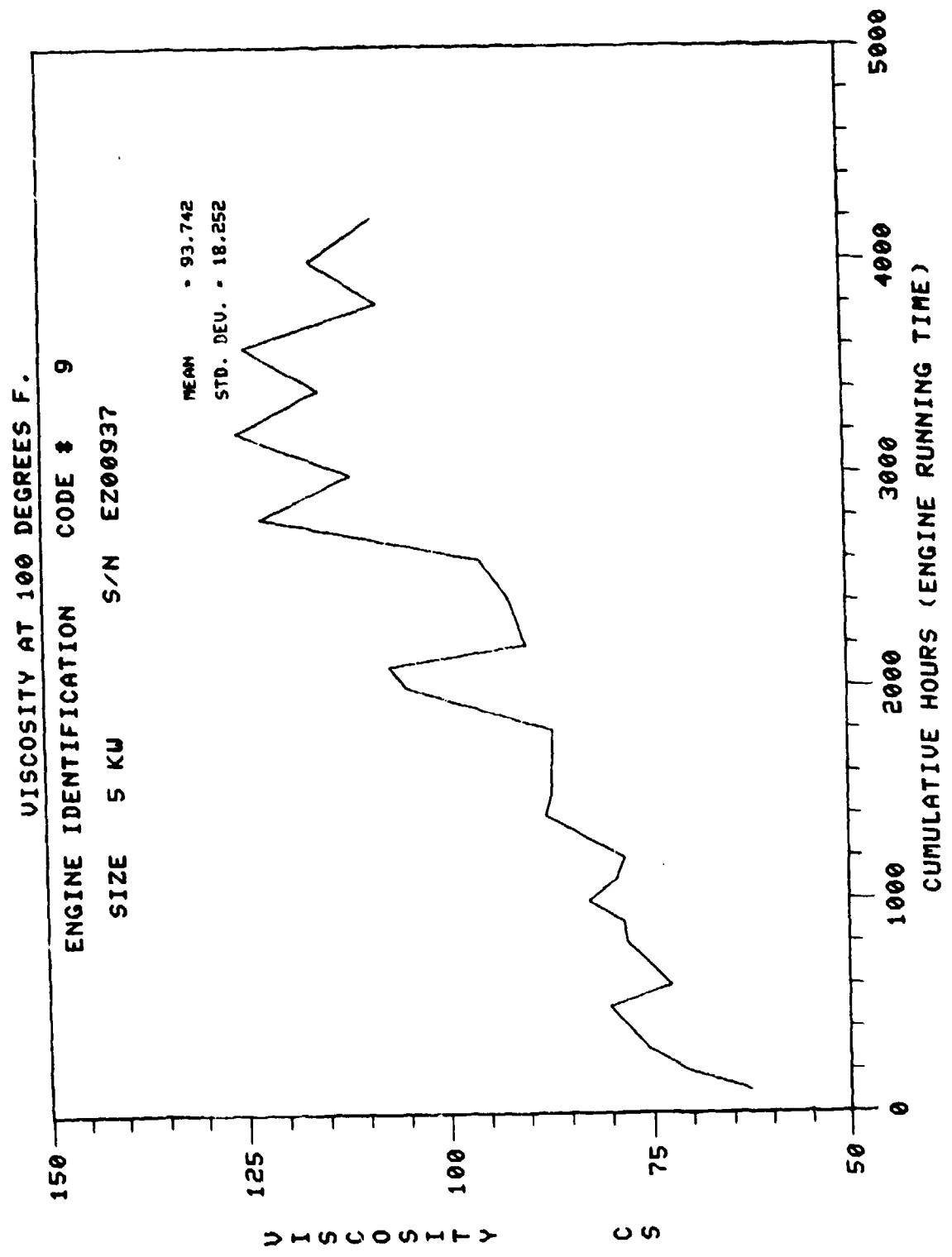


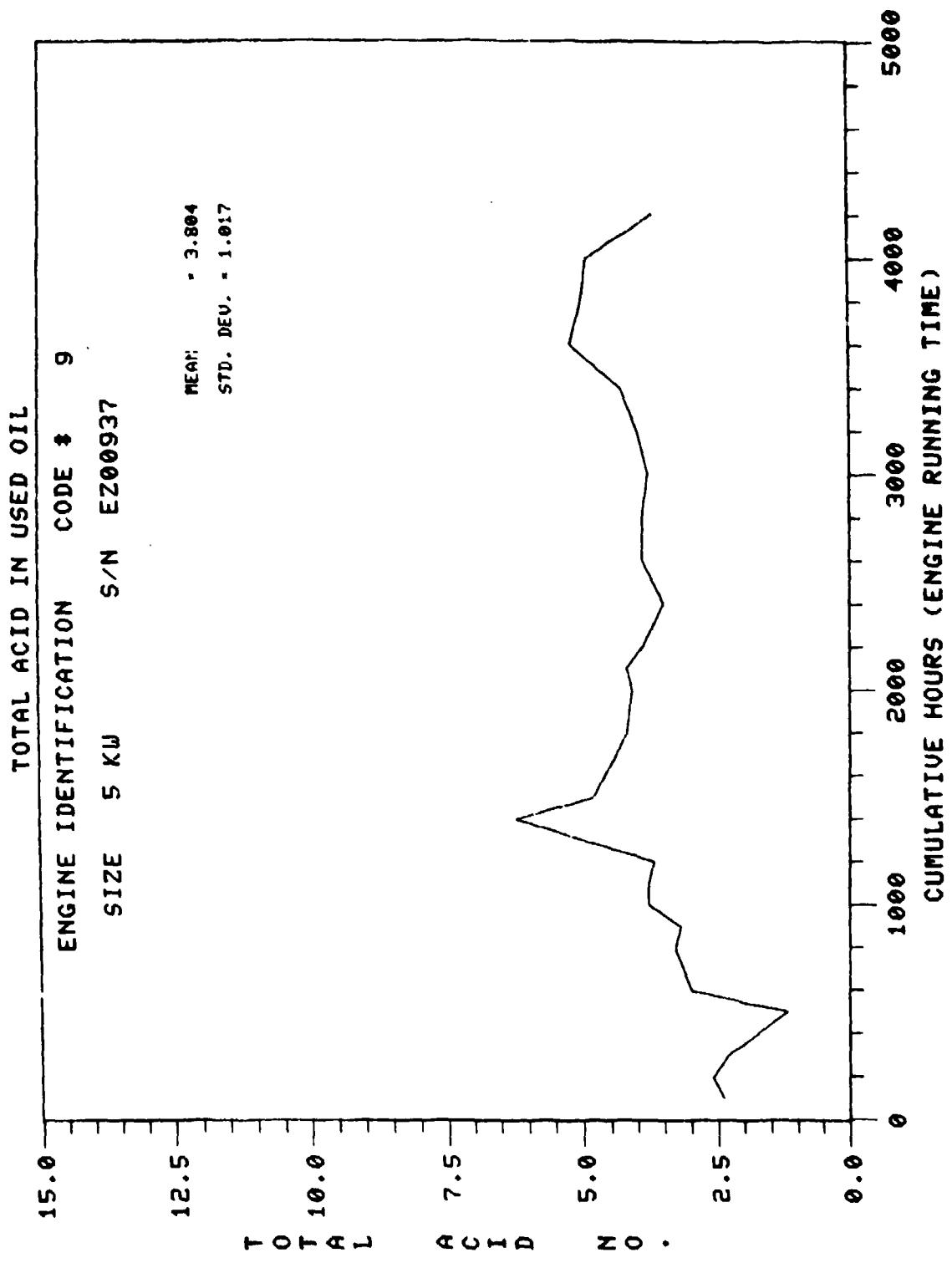












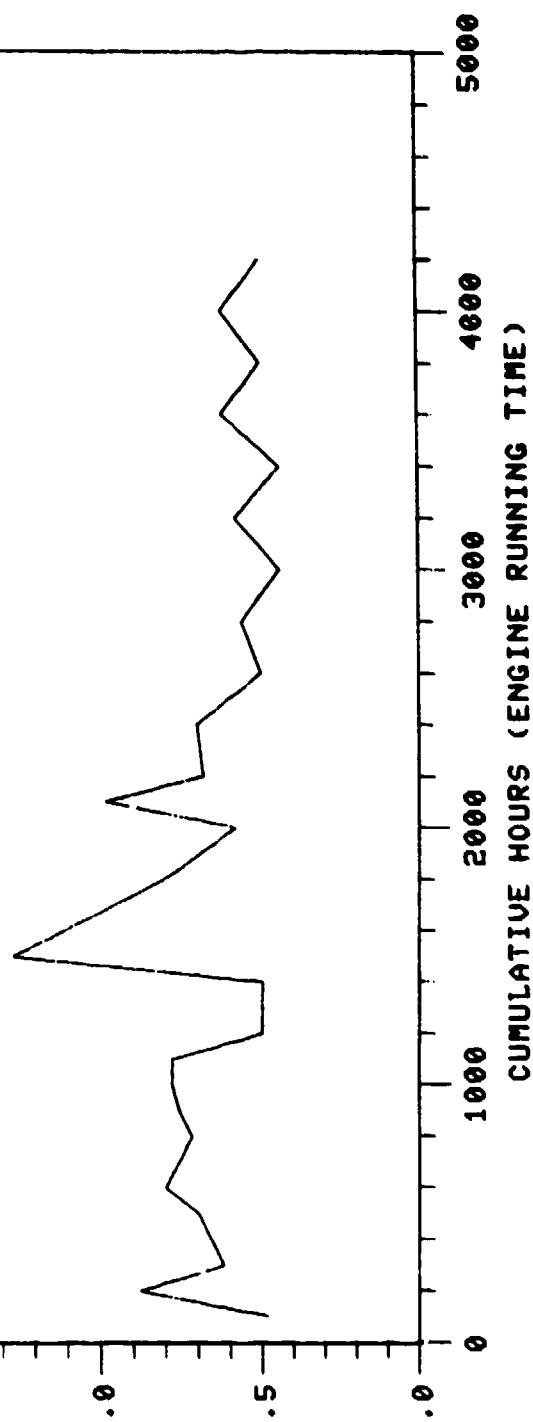
f.

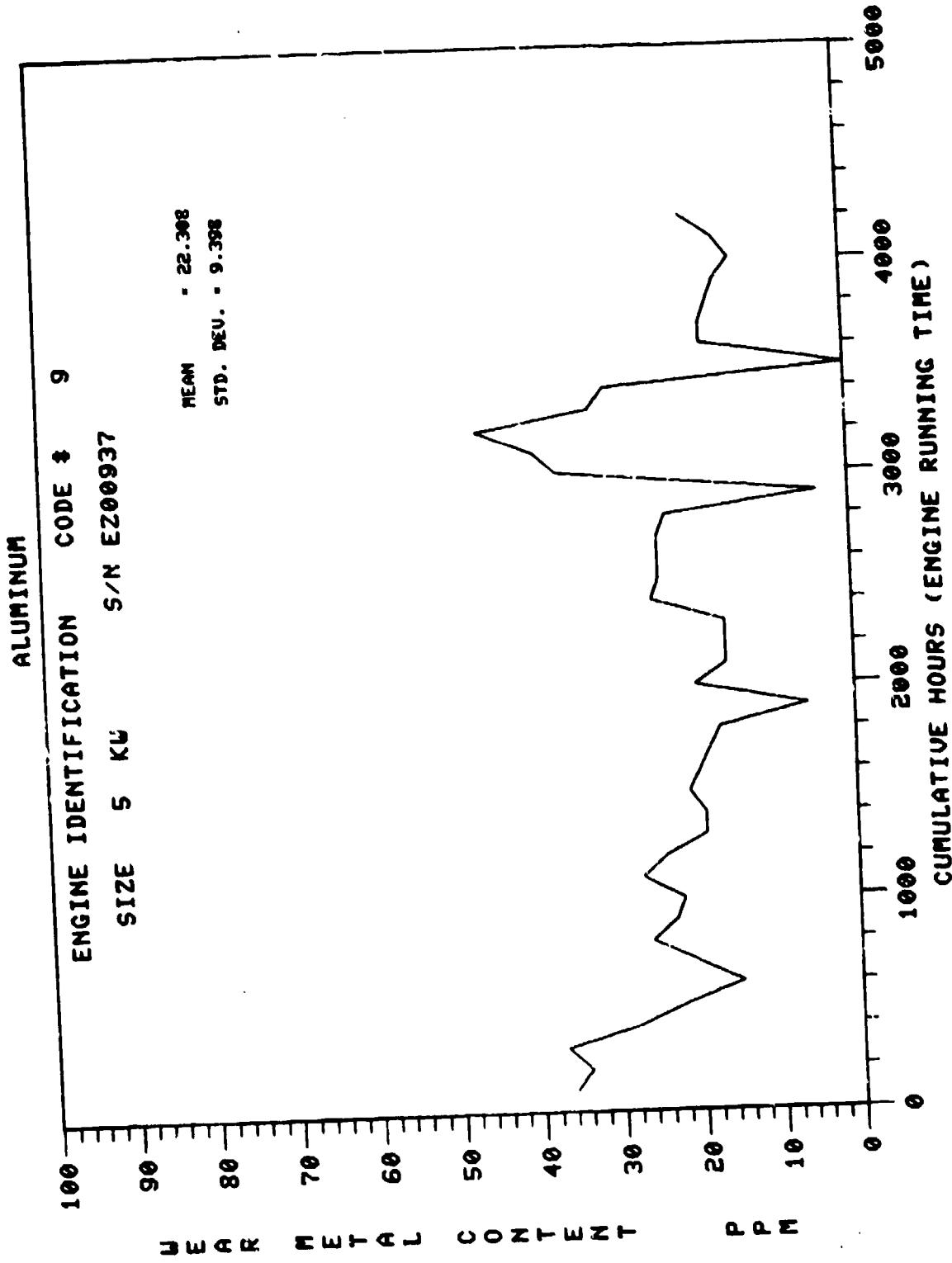
TOTAL BASE IN USED OIL

ENGINE IDENTIFICATION CODE # 9

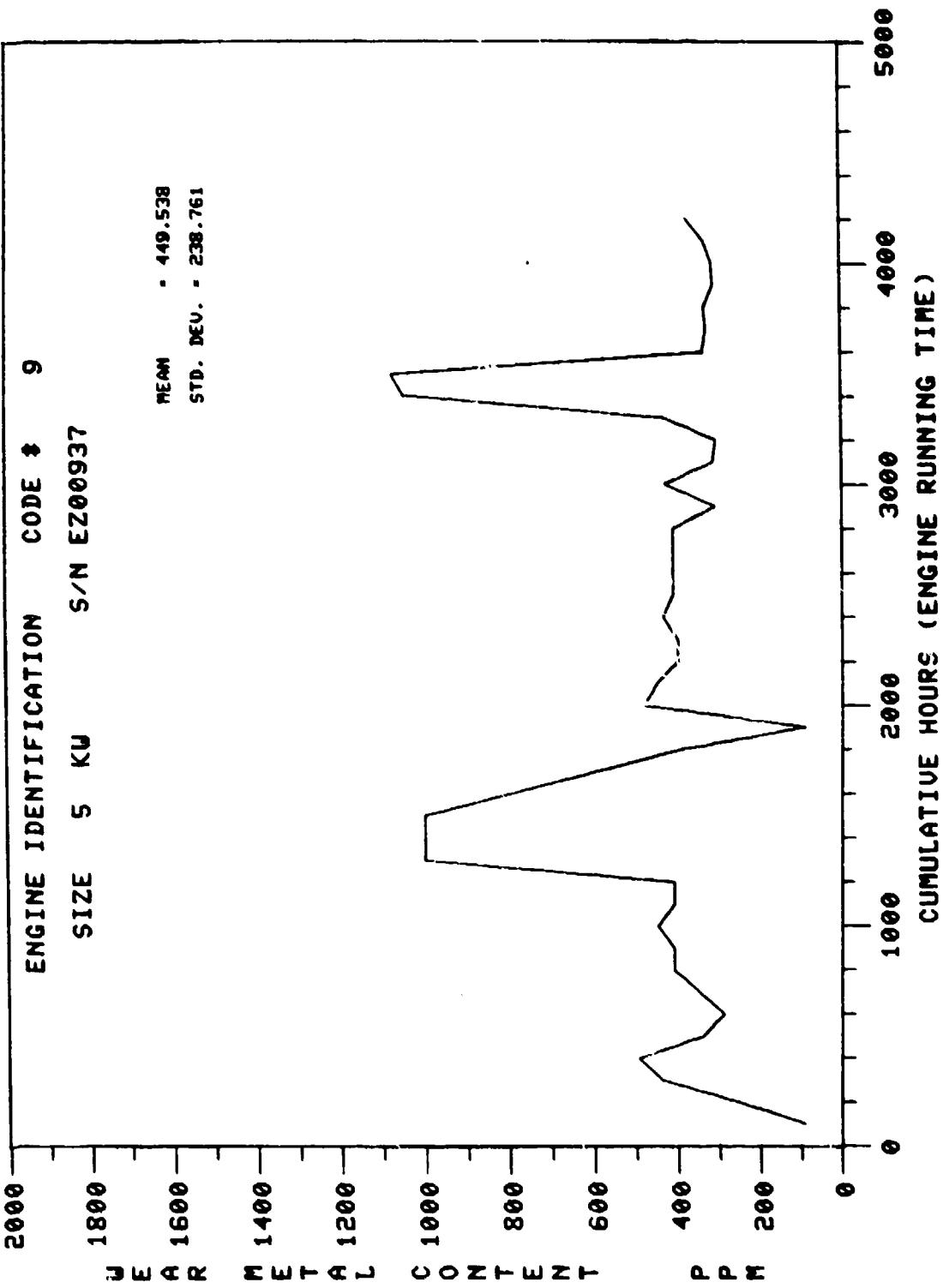
SIZE 5 KW S/N E200937

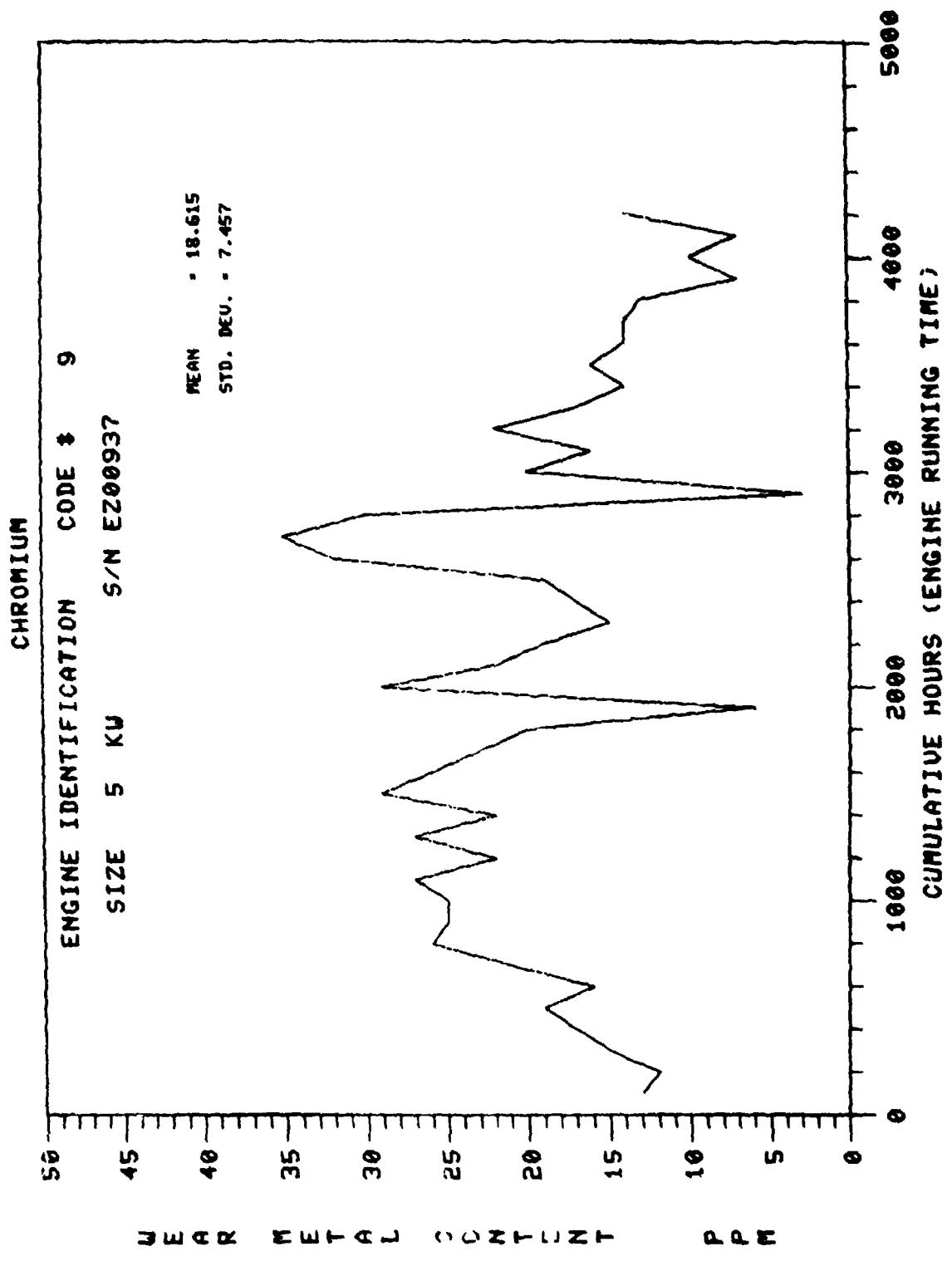
MEAN = 3.323
STD. DEV. = 0.938



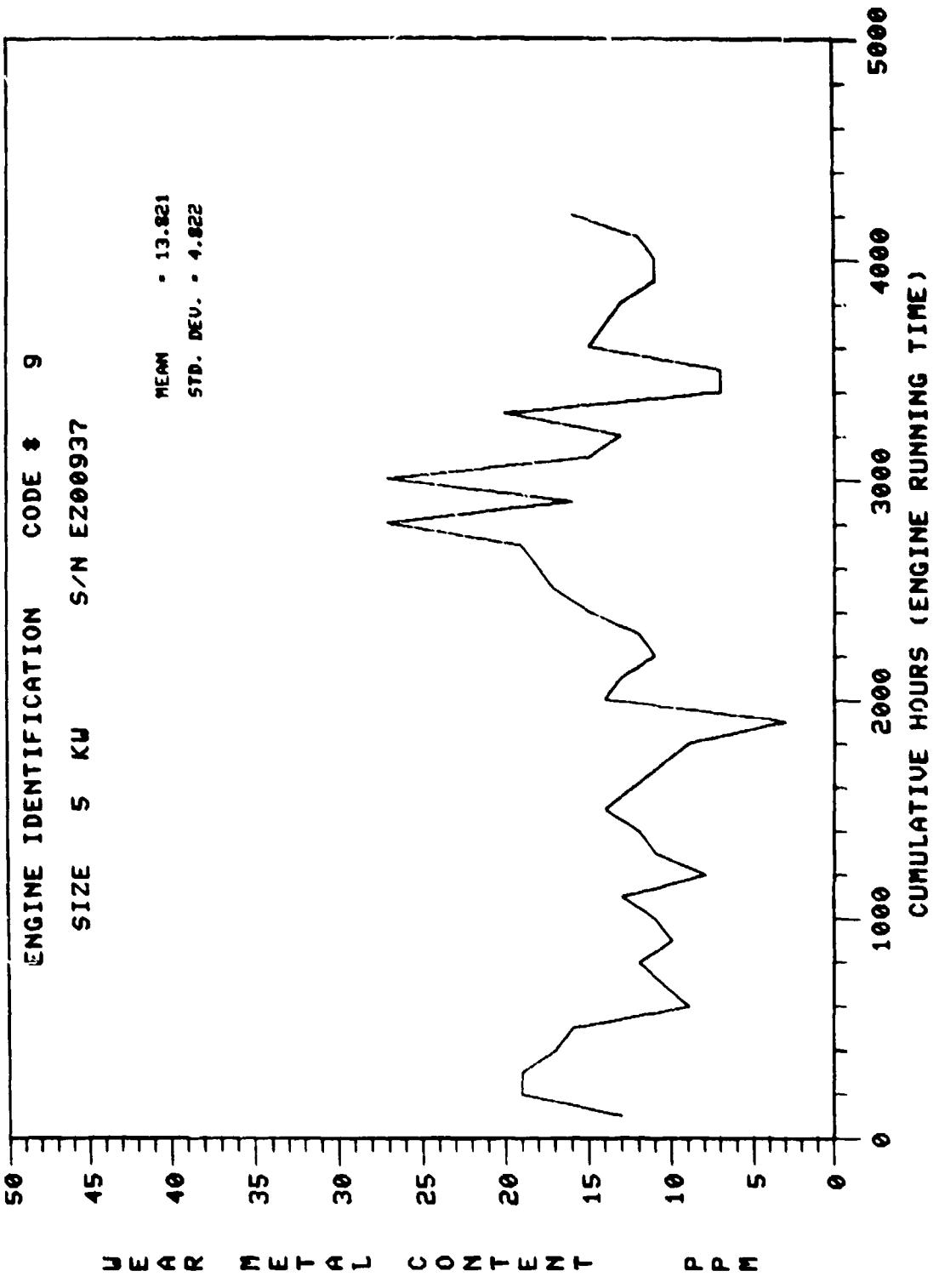


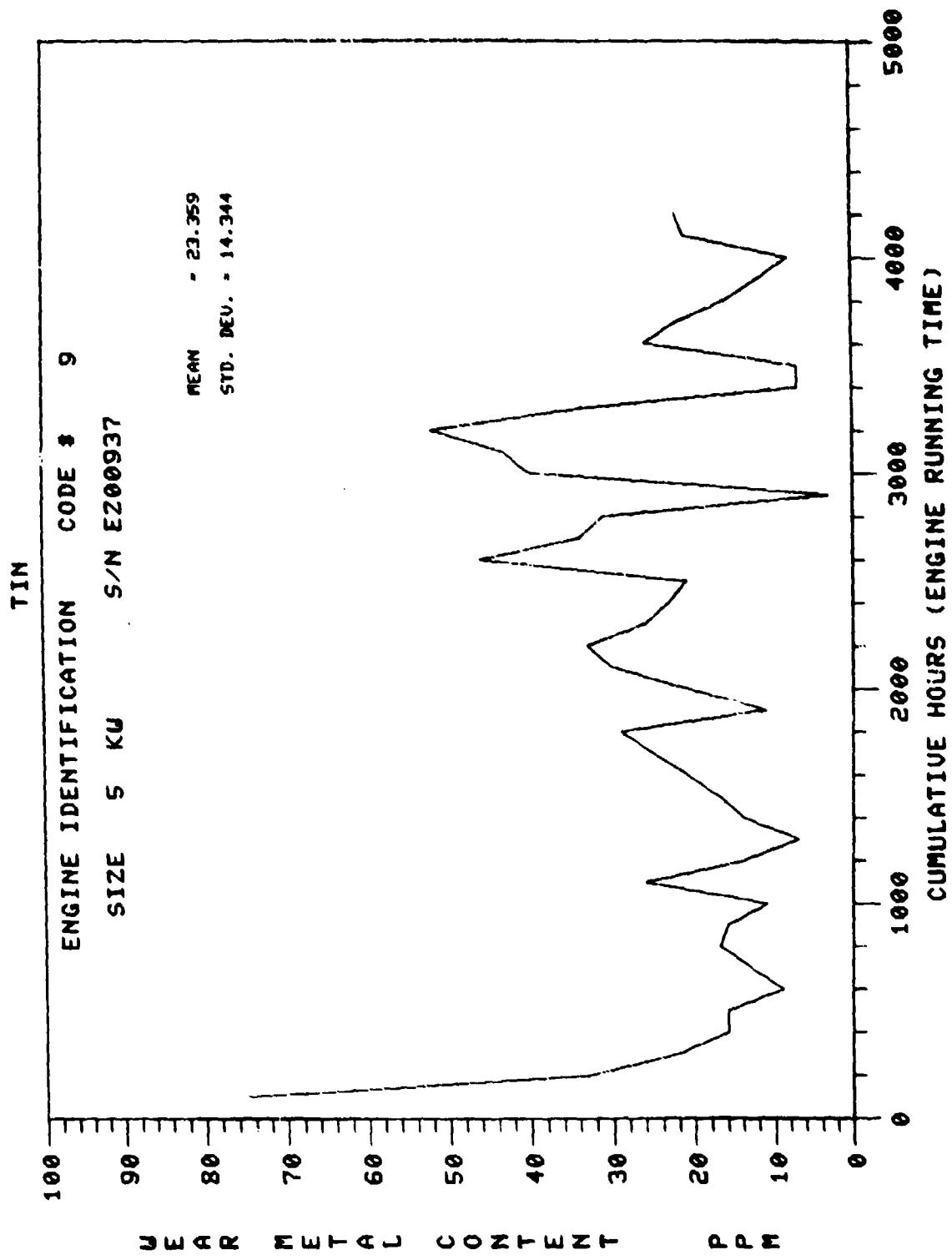
IRON

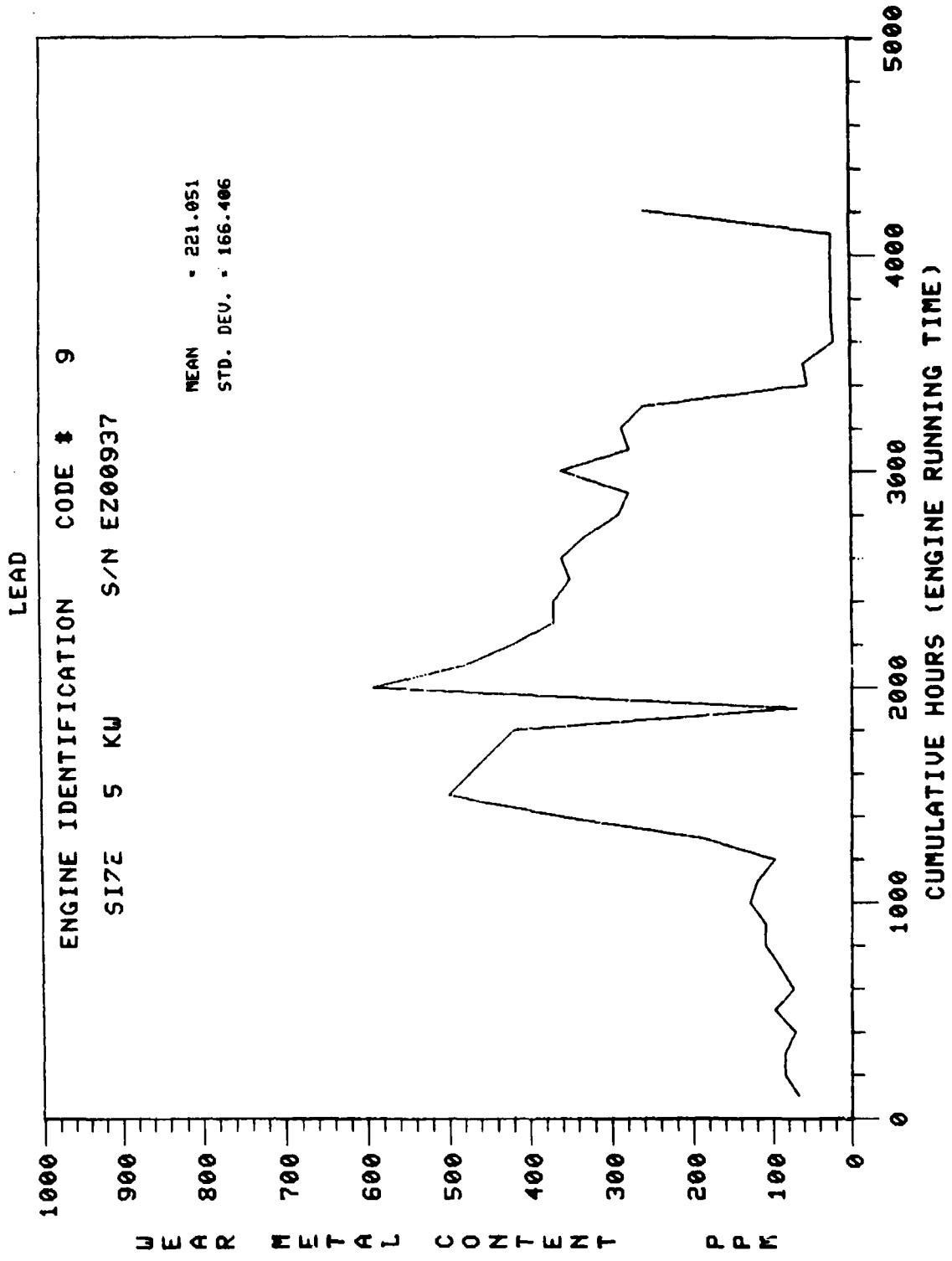


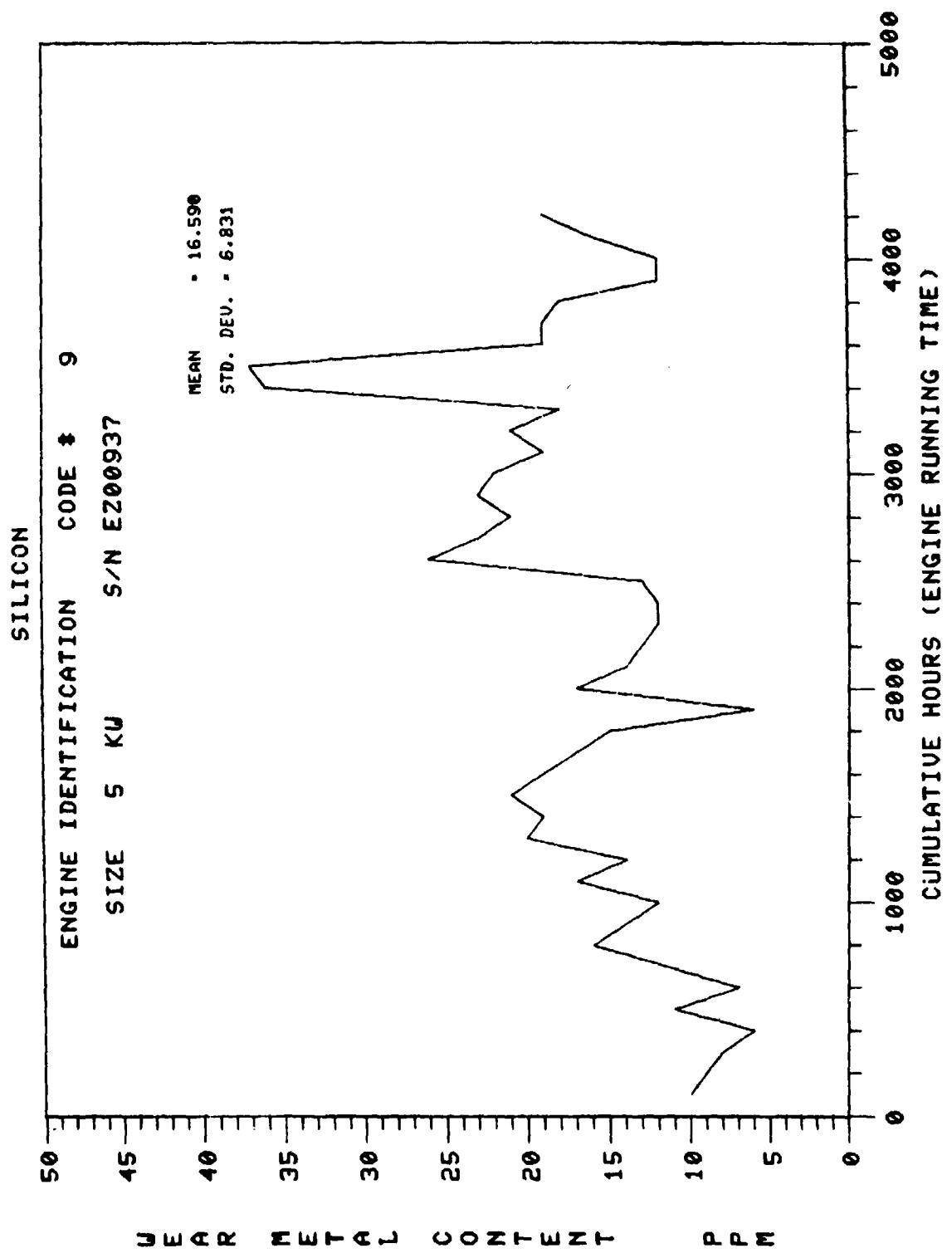


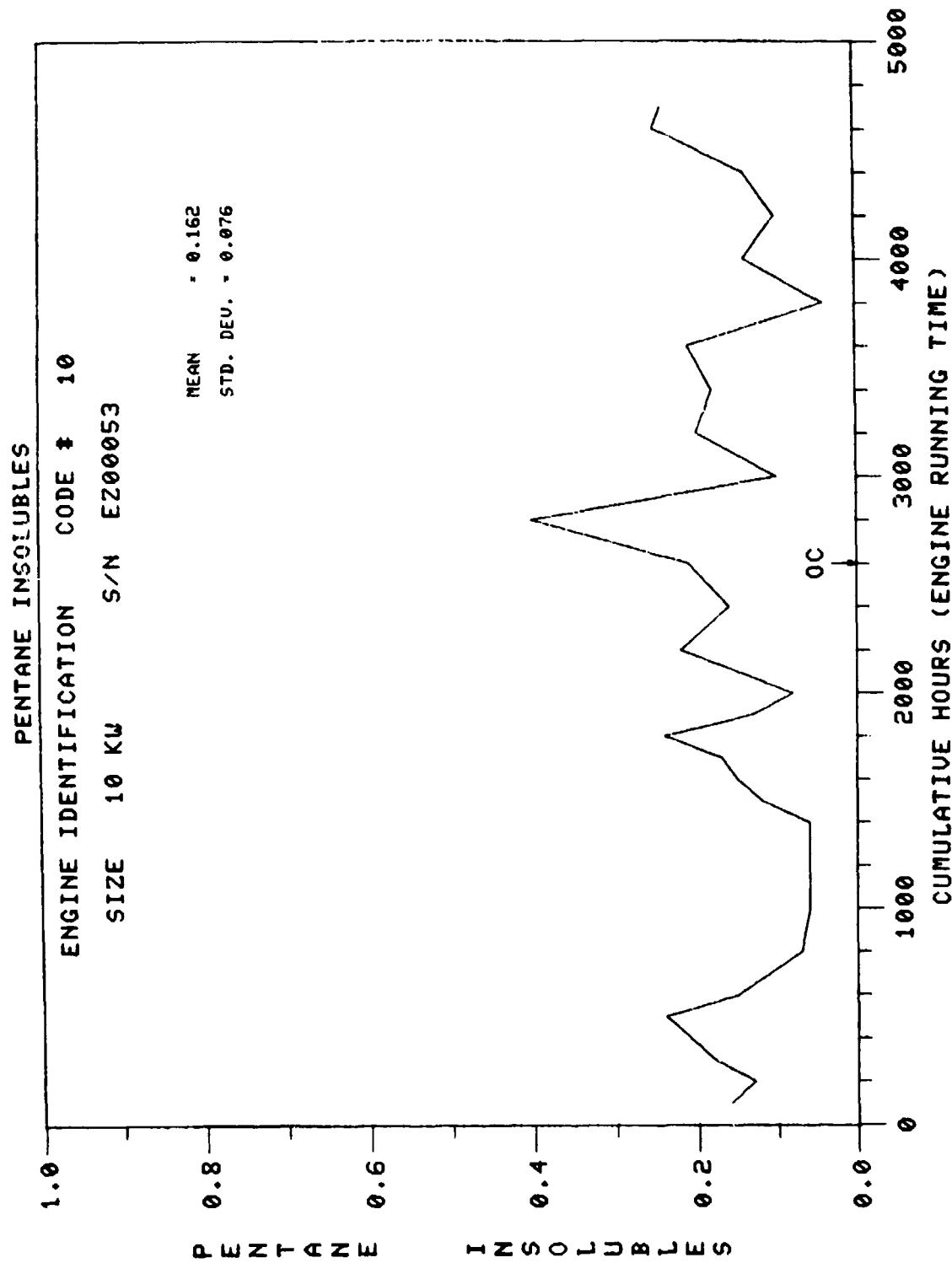
COPPER

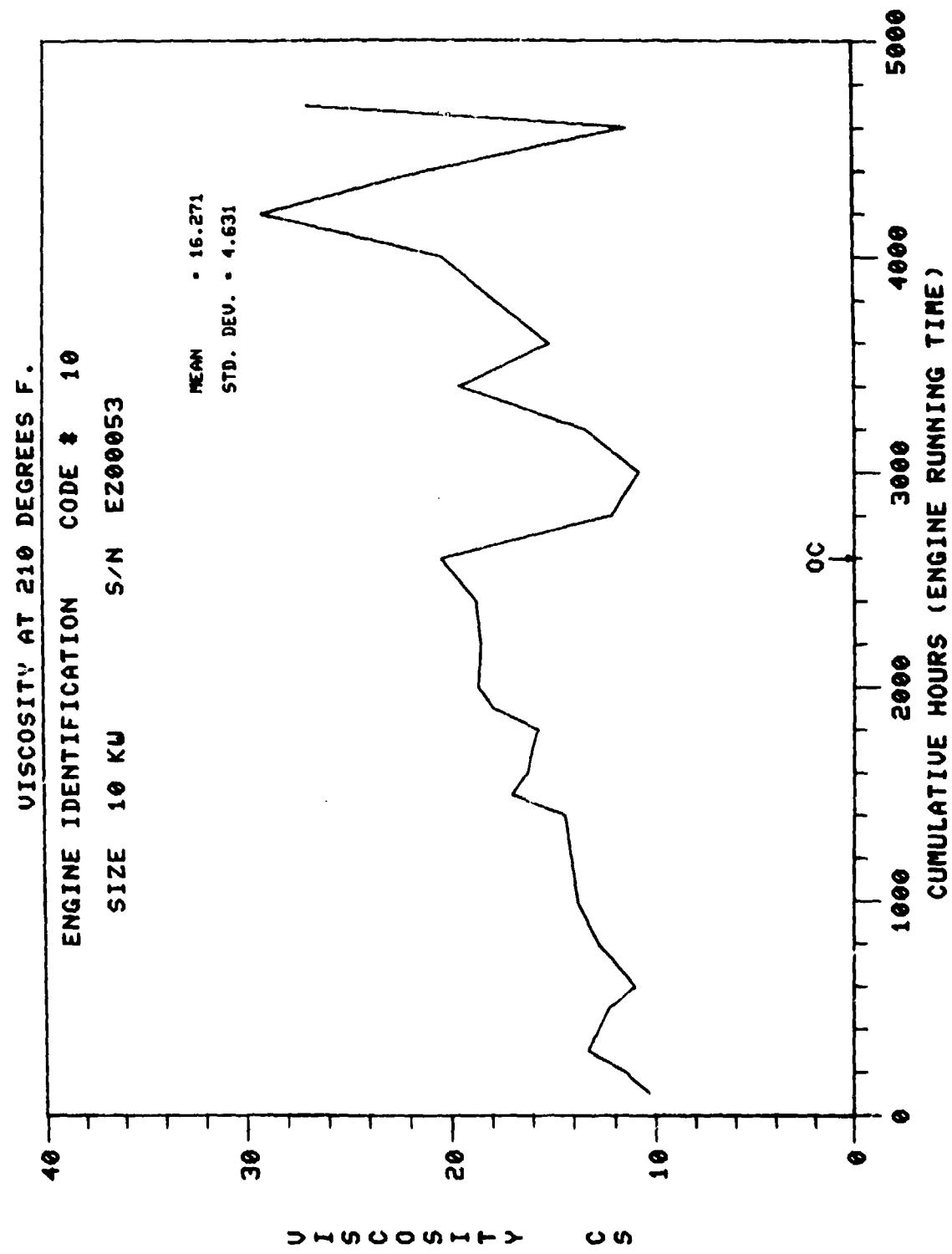










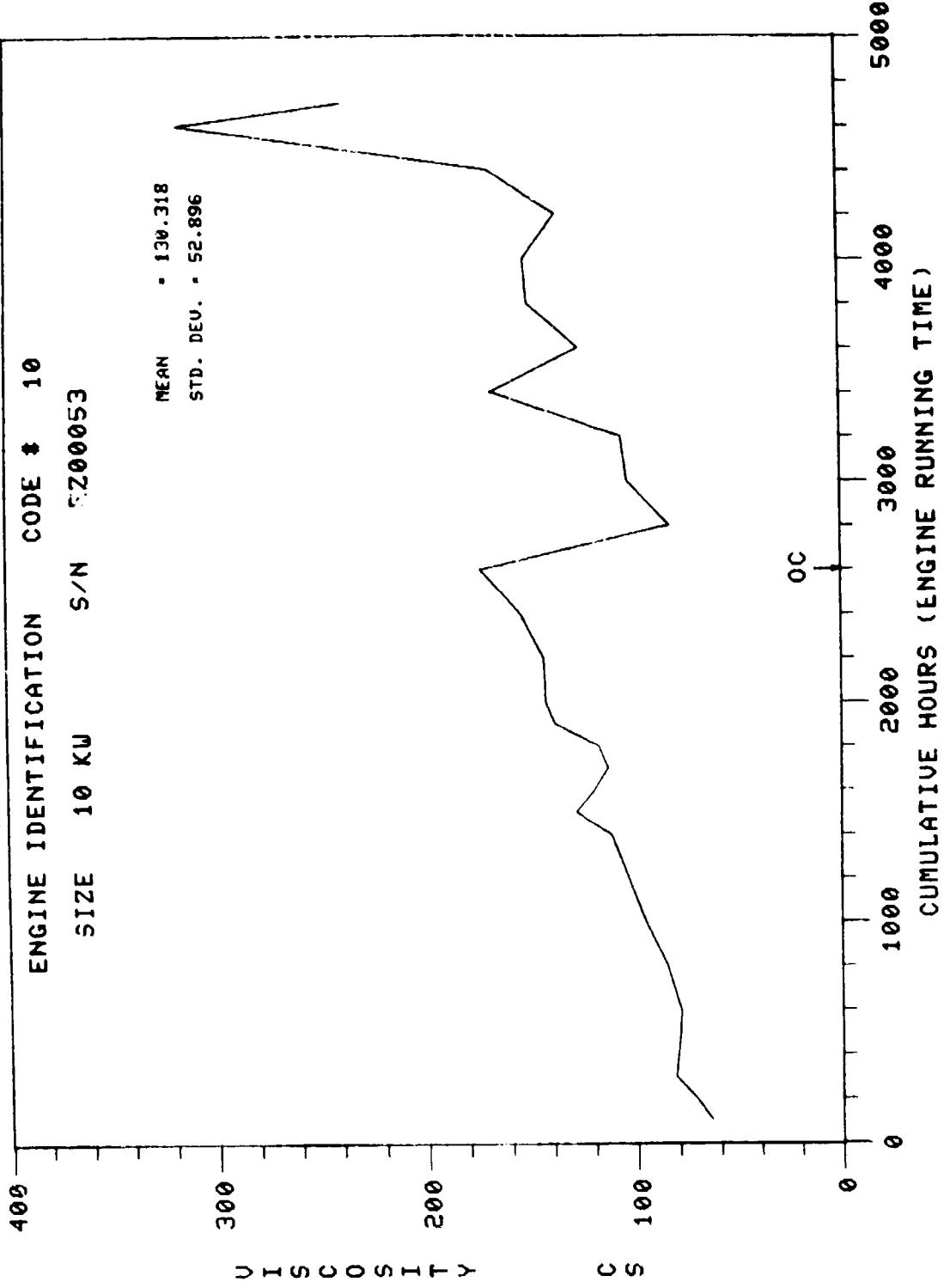


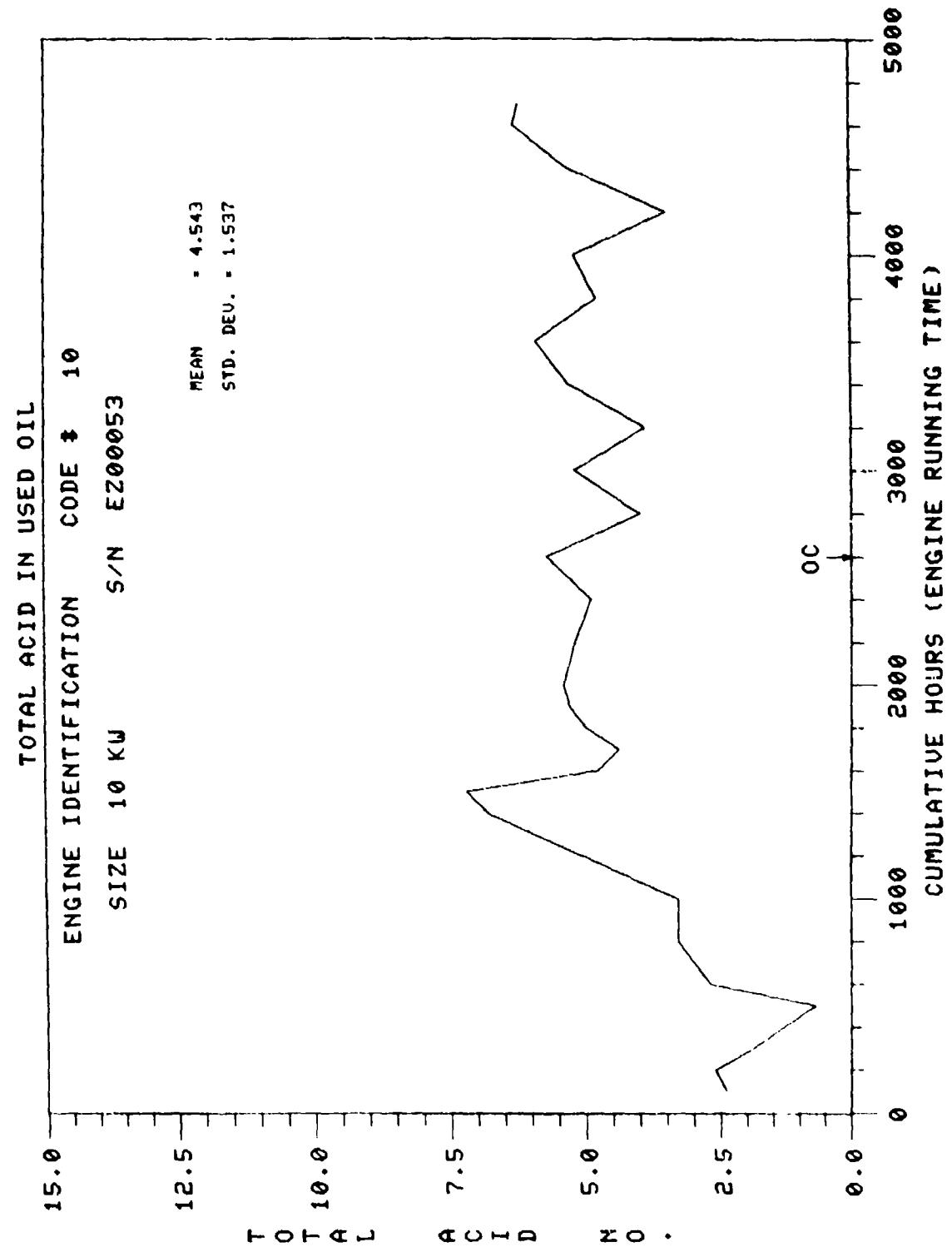
VISCOSITY AT 100 DEGREES F.

ENGINE IDENTIFICATION CODE # 10

SIZE 10 KW S/N 5200053

MEAN = 130.318
STD. DEV. = 52.896





TOTAL BASE IN USED OIL

ENGINE IDENTIFICATION CODE # 10

SIZE 10 KU S/N EZ00053

MEAN = 2.500
STD. DEV. = 1.437

T 10.0
A L

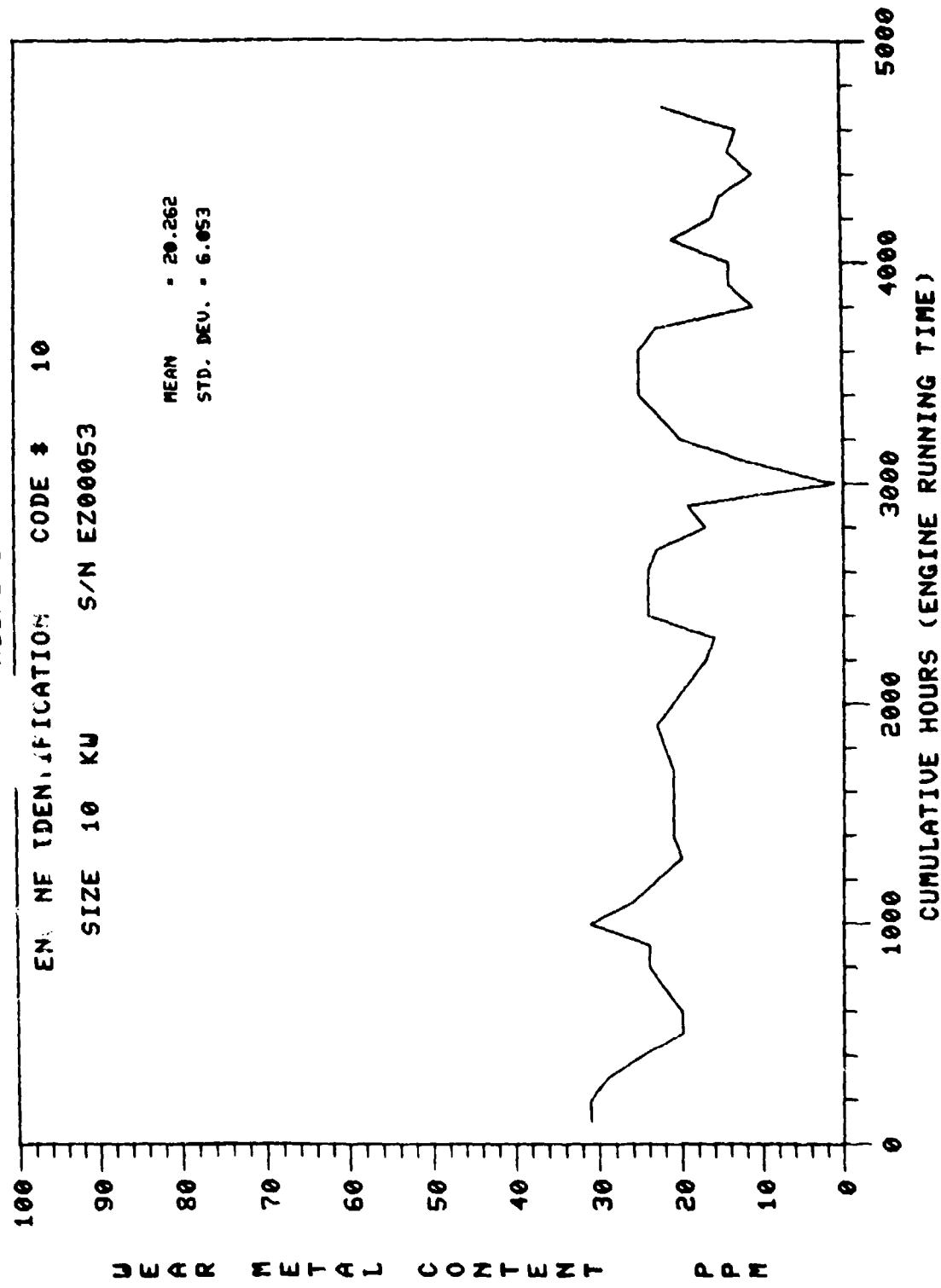
B 7.5
A S E

N O .

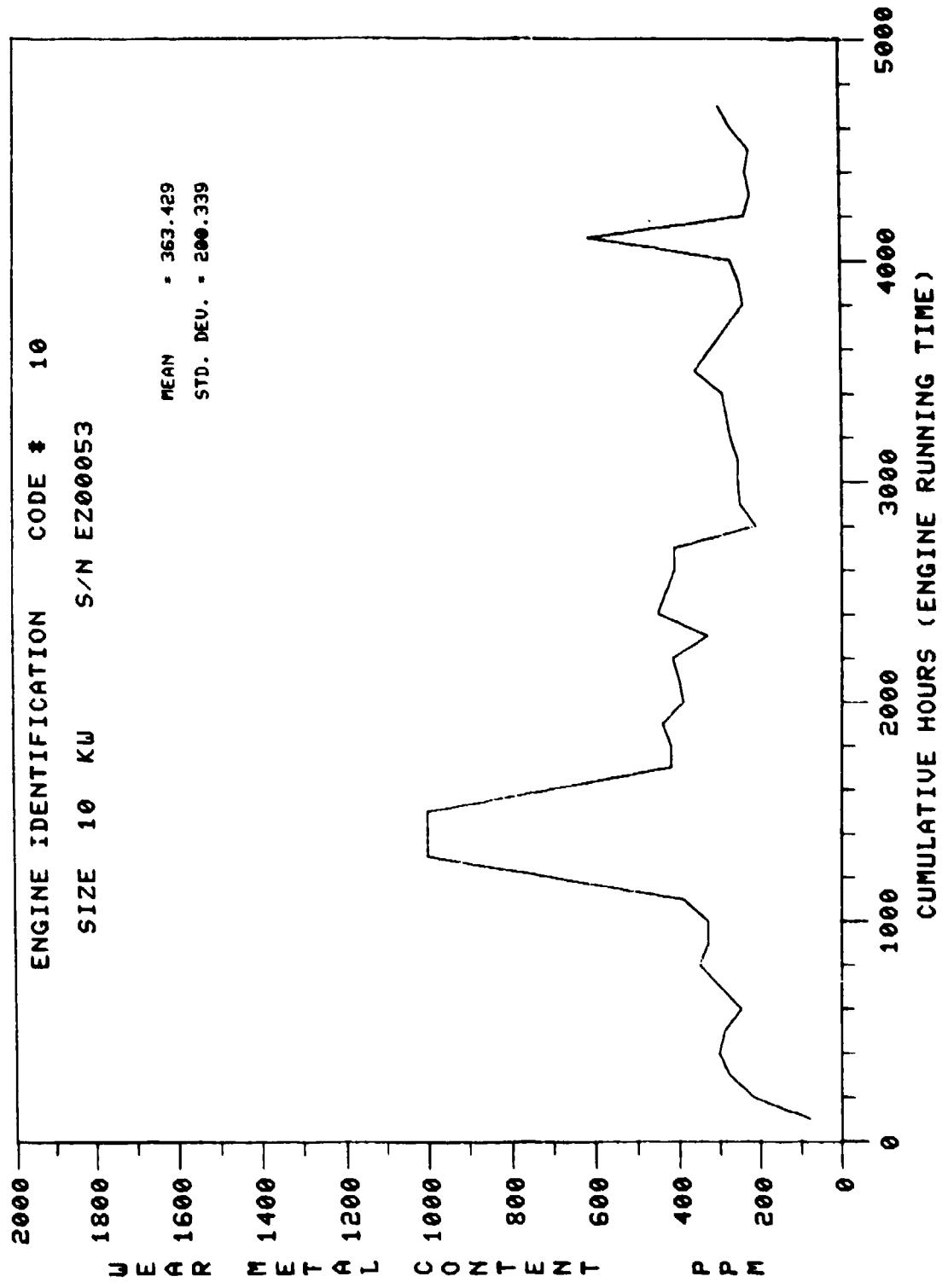
120



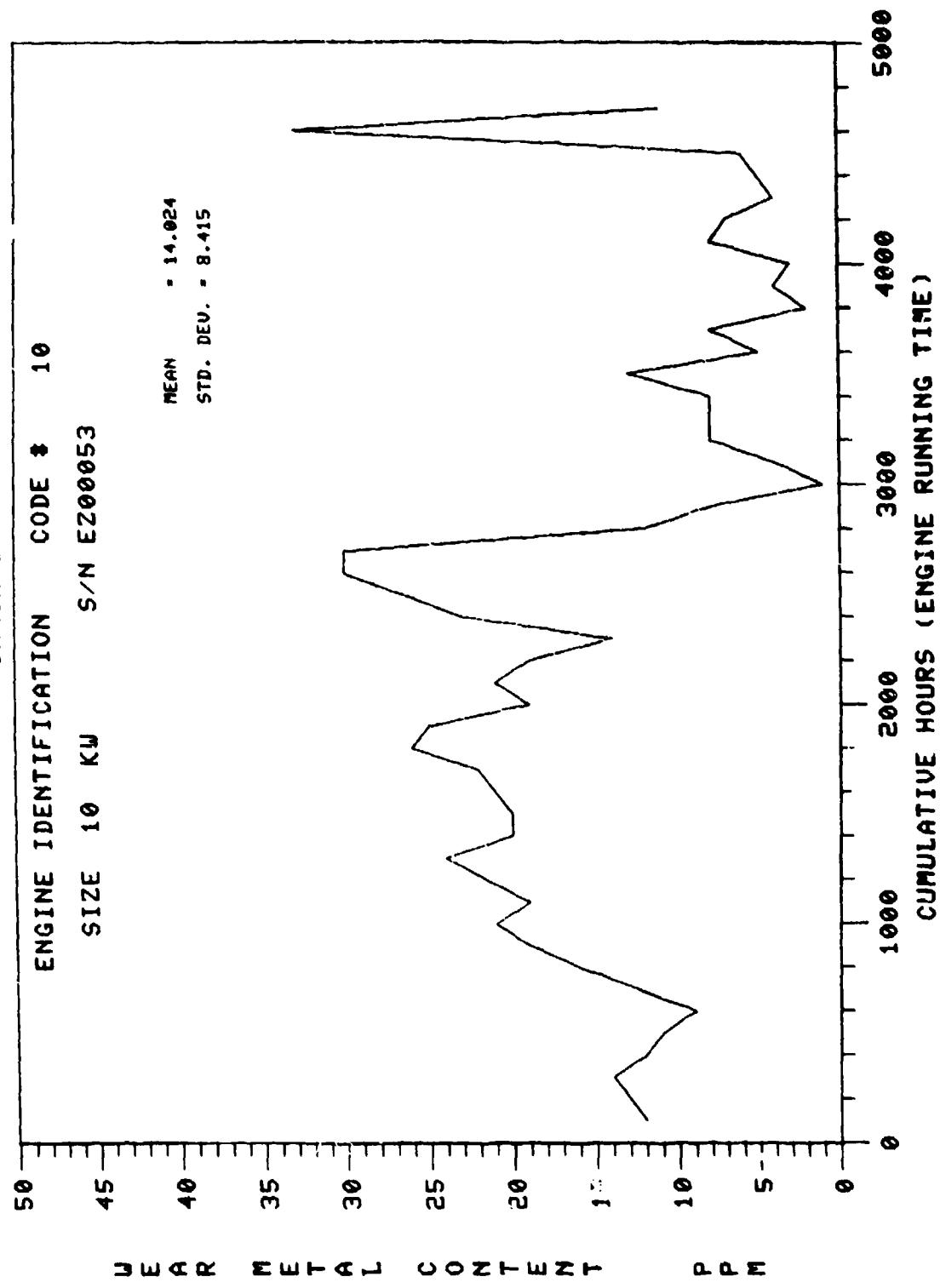
ALUMINUM



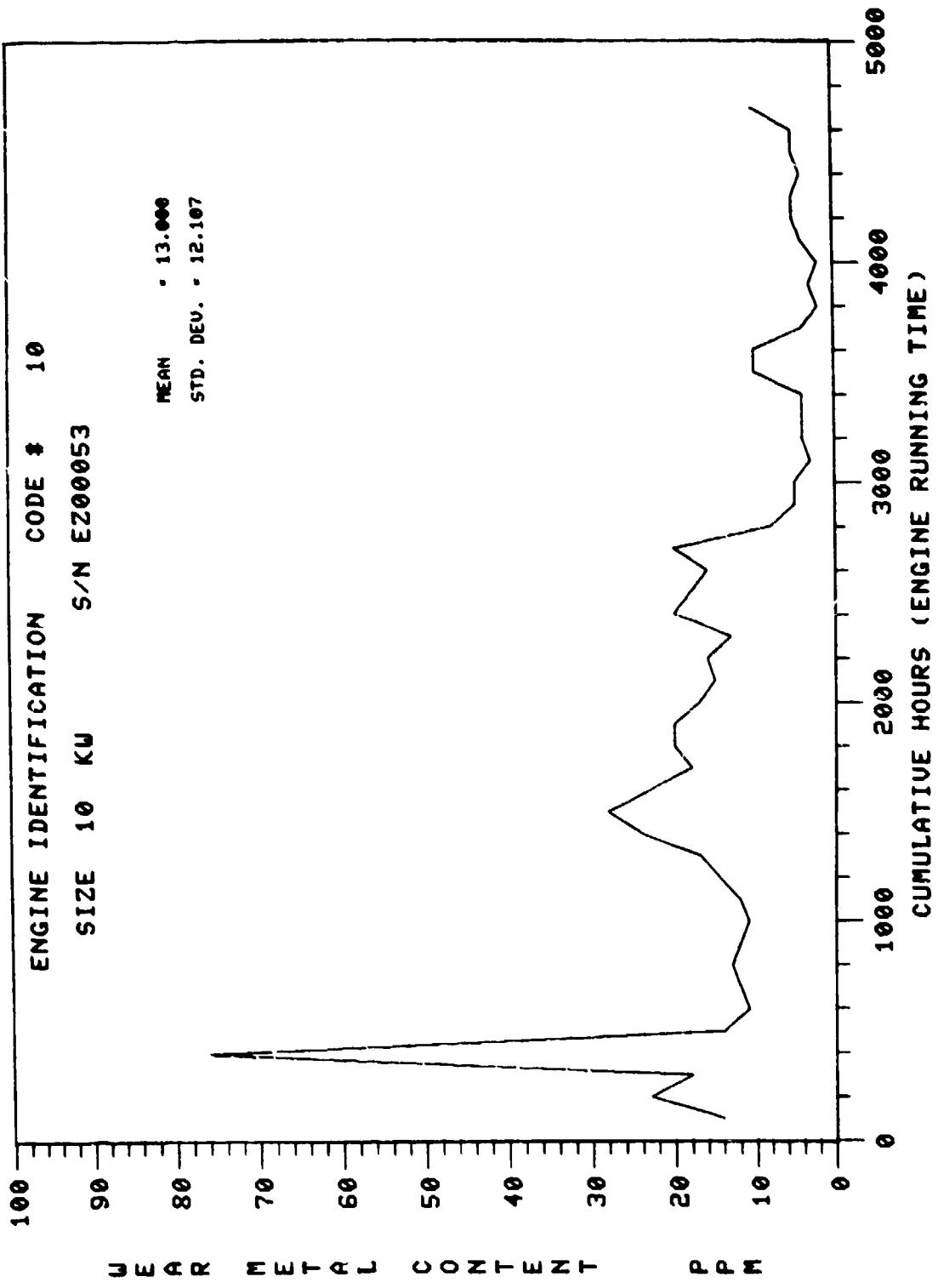
IRON

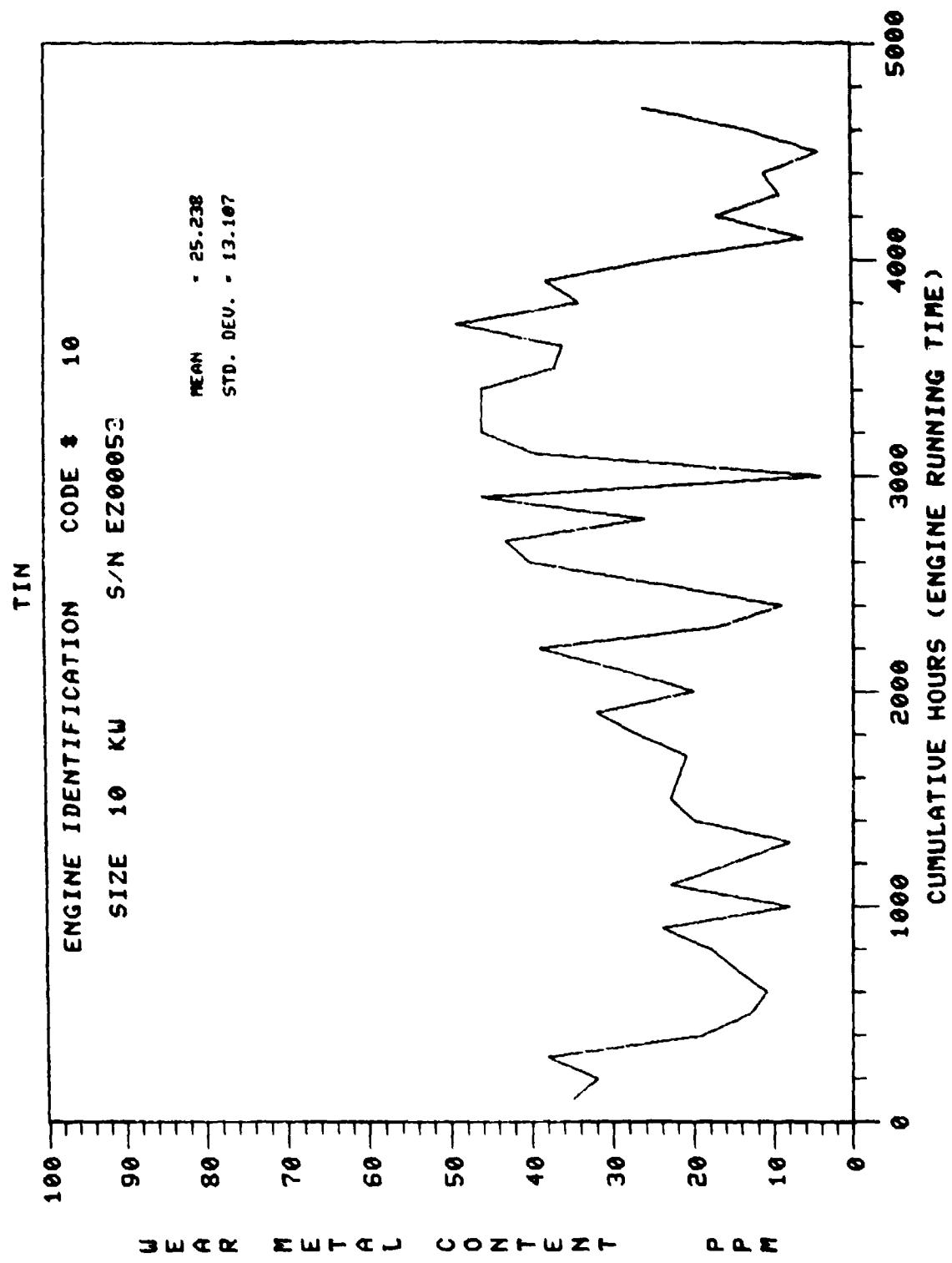


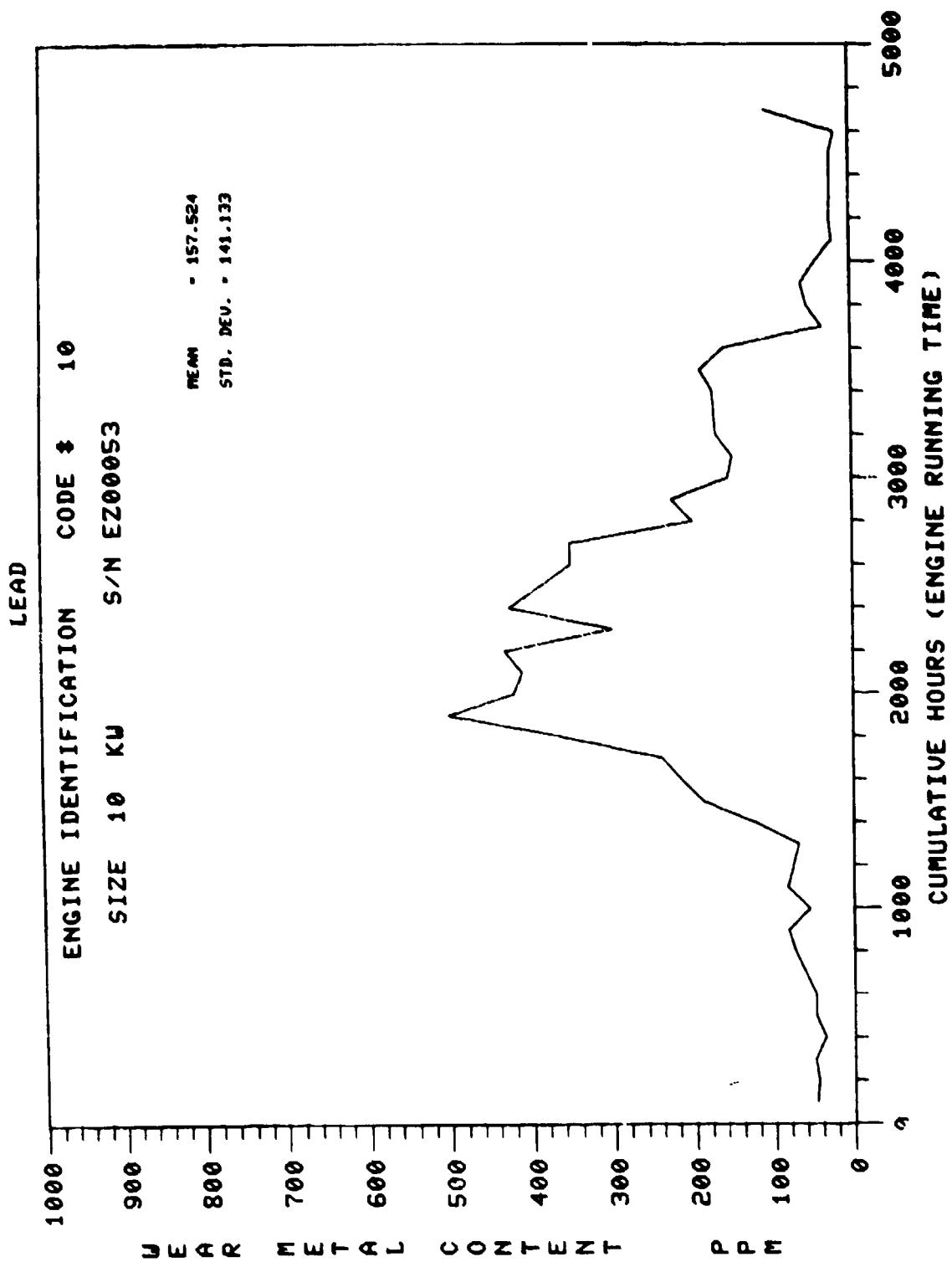
CHROMIUM

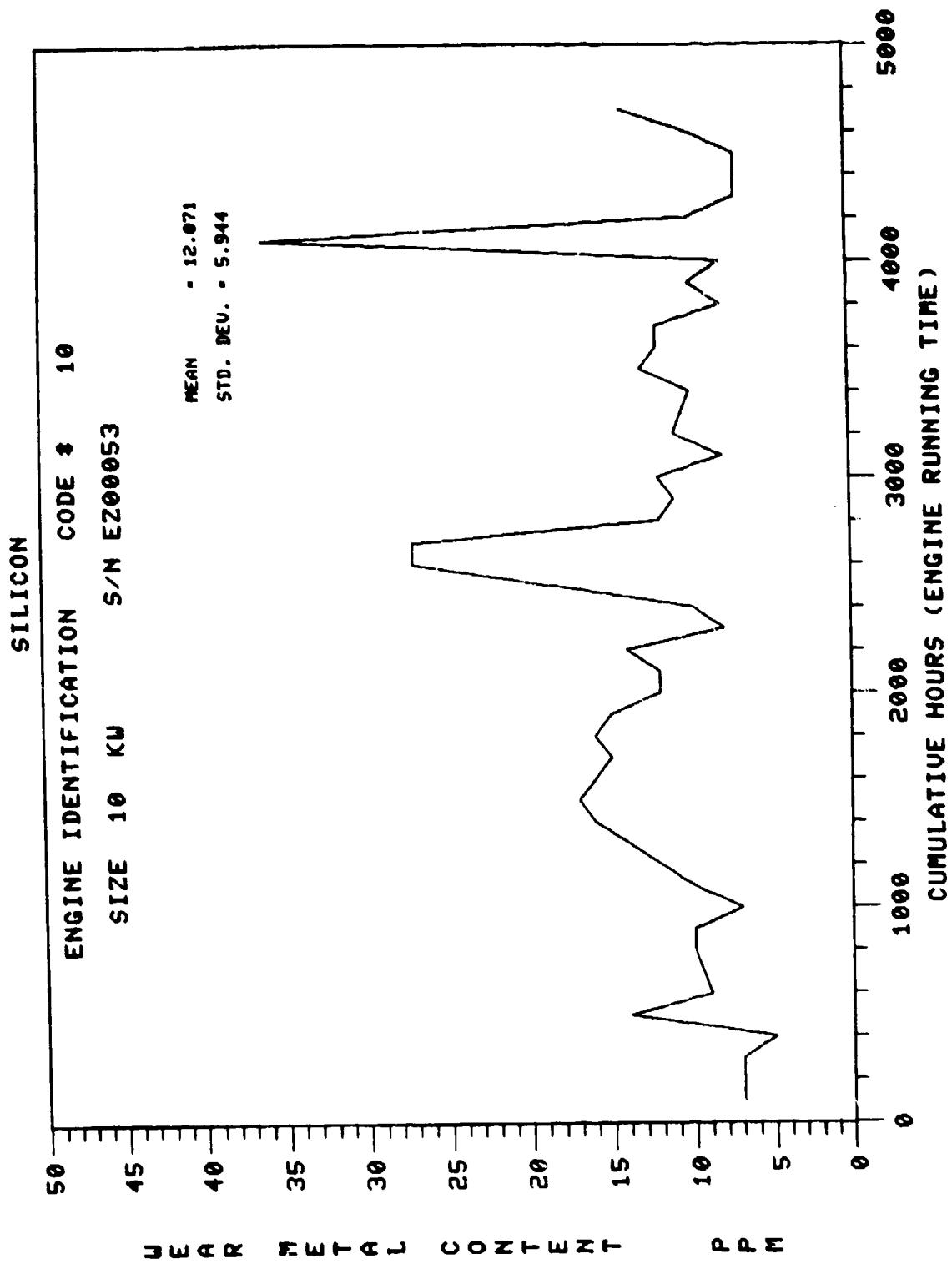


COPPER









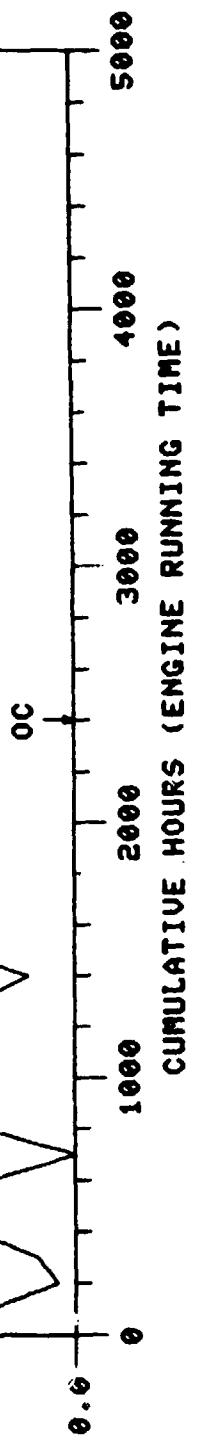
PENTANE INSOLUBLES

ENGINE IDENTIFICATION CODE # 11

SIZE 15 KW S/N R221277

MEAN = 0.141
STD. DEV. = 0.087

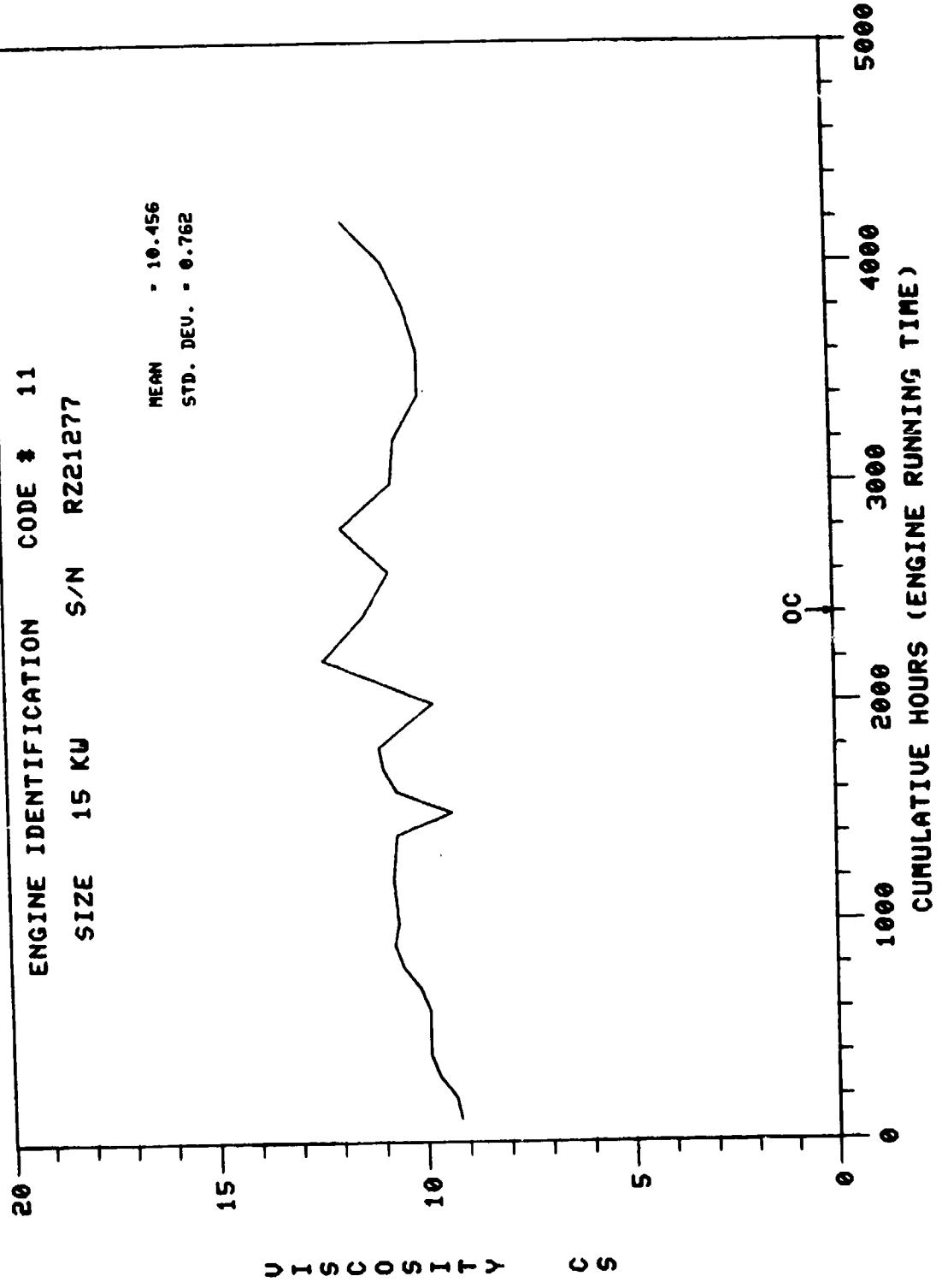
P E N T A N E I N S O L U B L E S



VISCOOSITY AT 210 DEGREES F.

ENGINE IDENTIFICATION CODE # 11
SIZE 15 KU S/N RZ21277

MEAN = 10.456
STD. DEV. = 0.762



VISCOOSITY AT 100 DEGREES F.

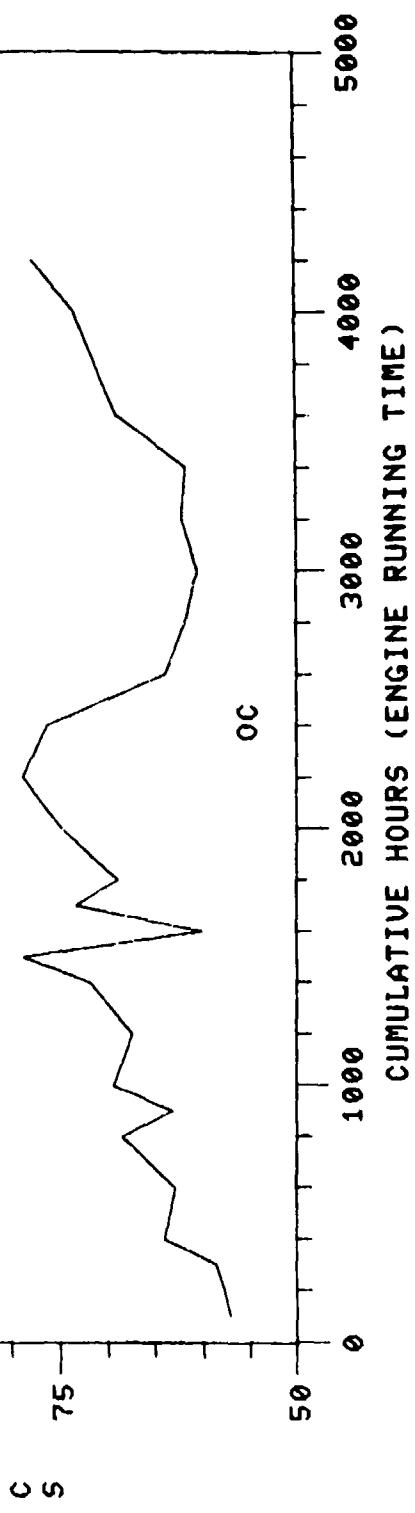
ENGINE IDENTIFICATION CODE # 11

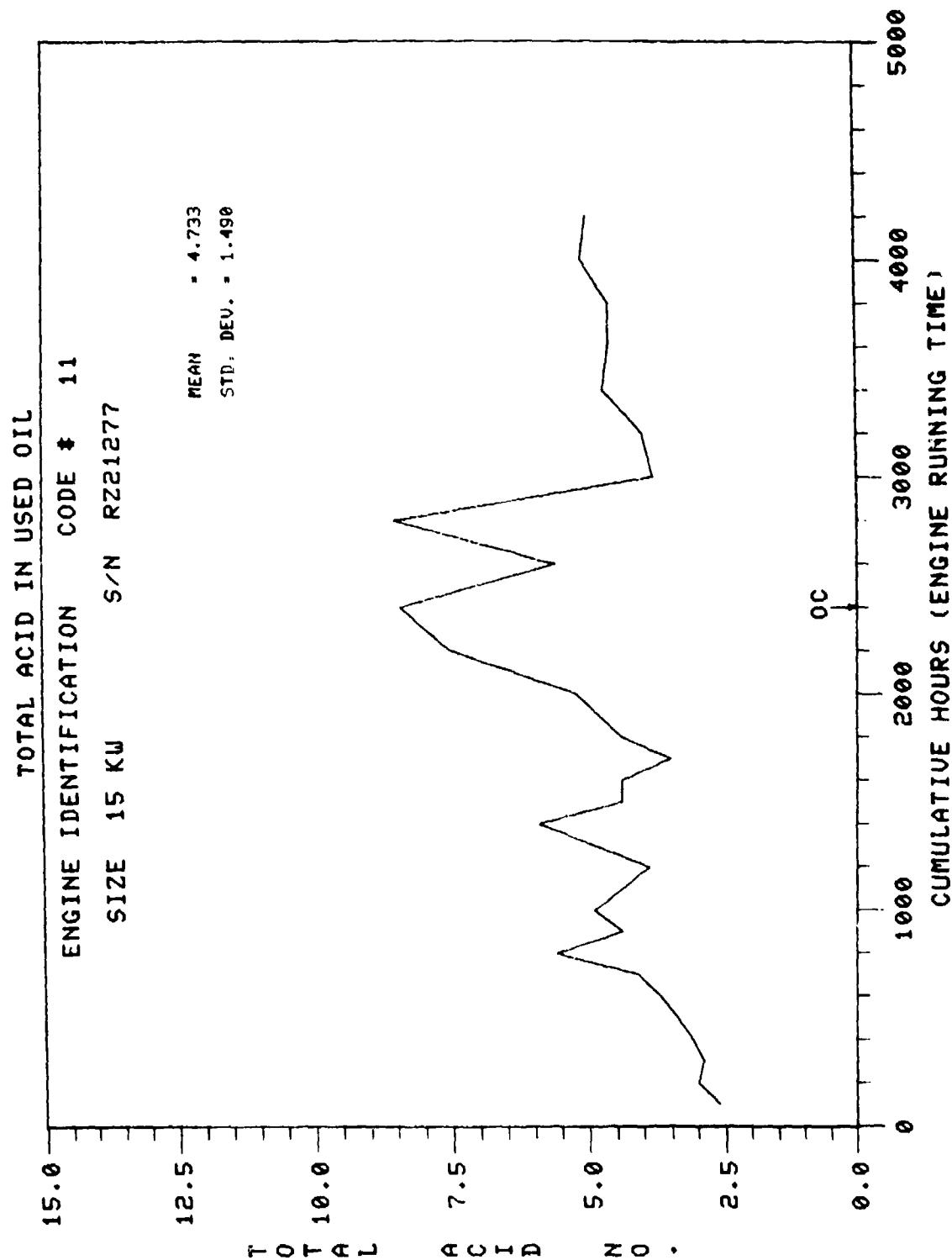
SIZE 15 KW S/N RZ21277

MEAN = 67.312
STD. DEV. = 6.619

VISCOOSITY

130





TOTAL BASE IN USED OIL

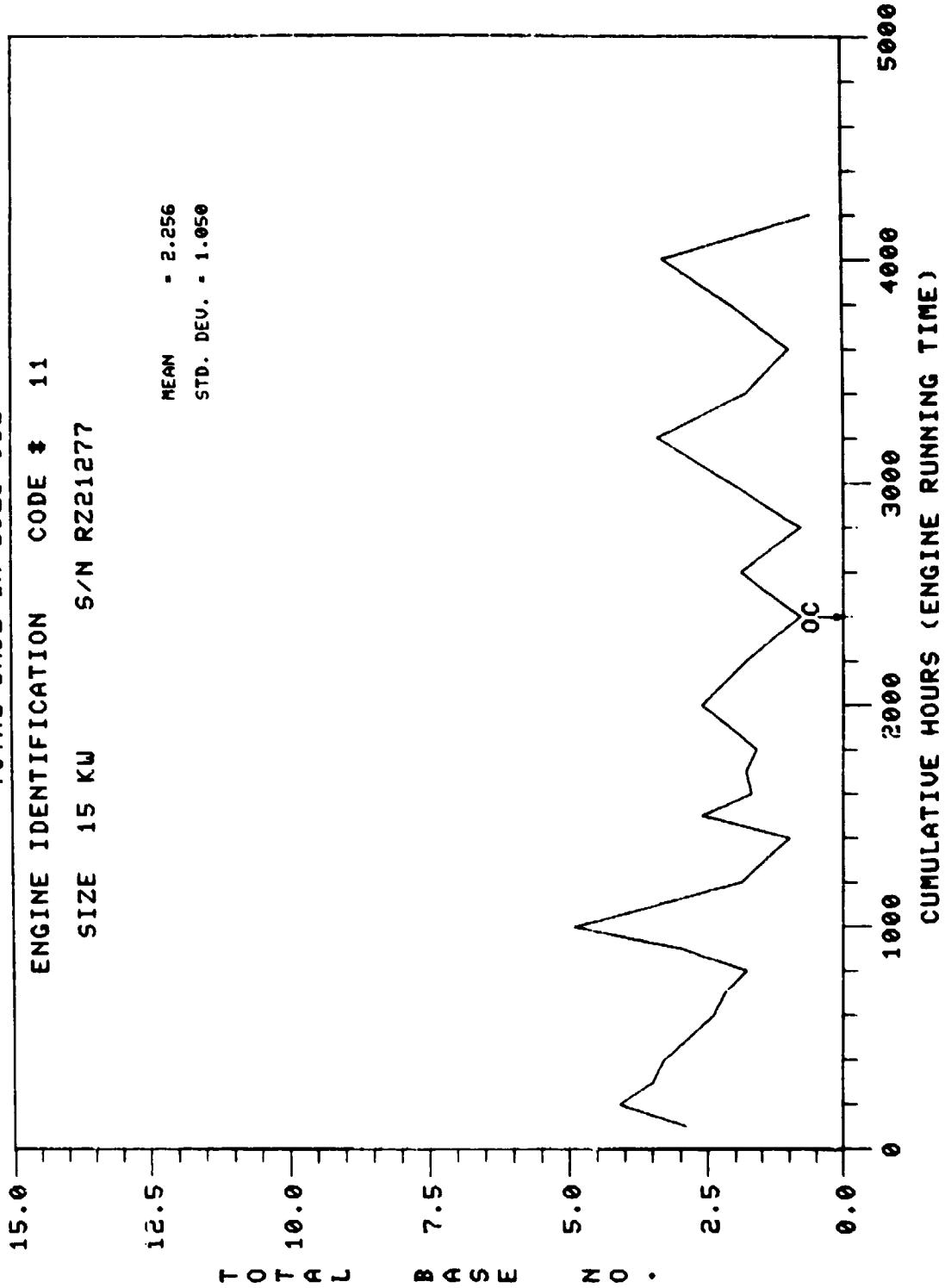
ENGINE IDENTIFICATION CODE # 11

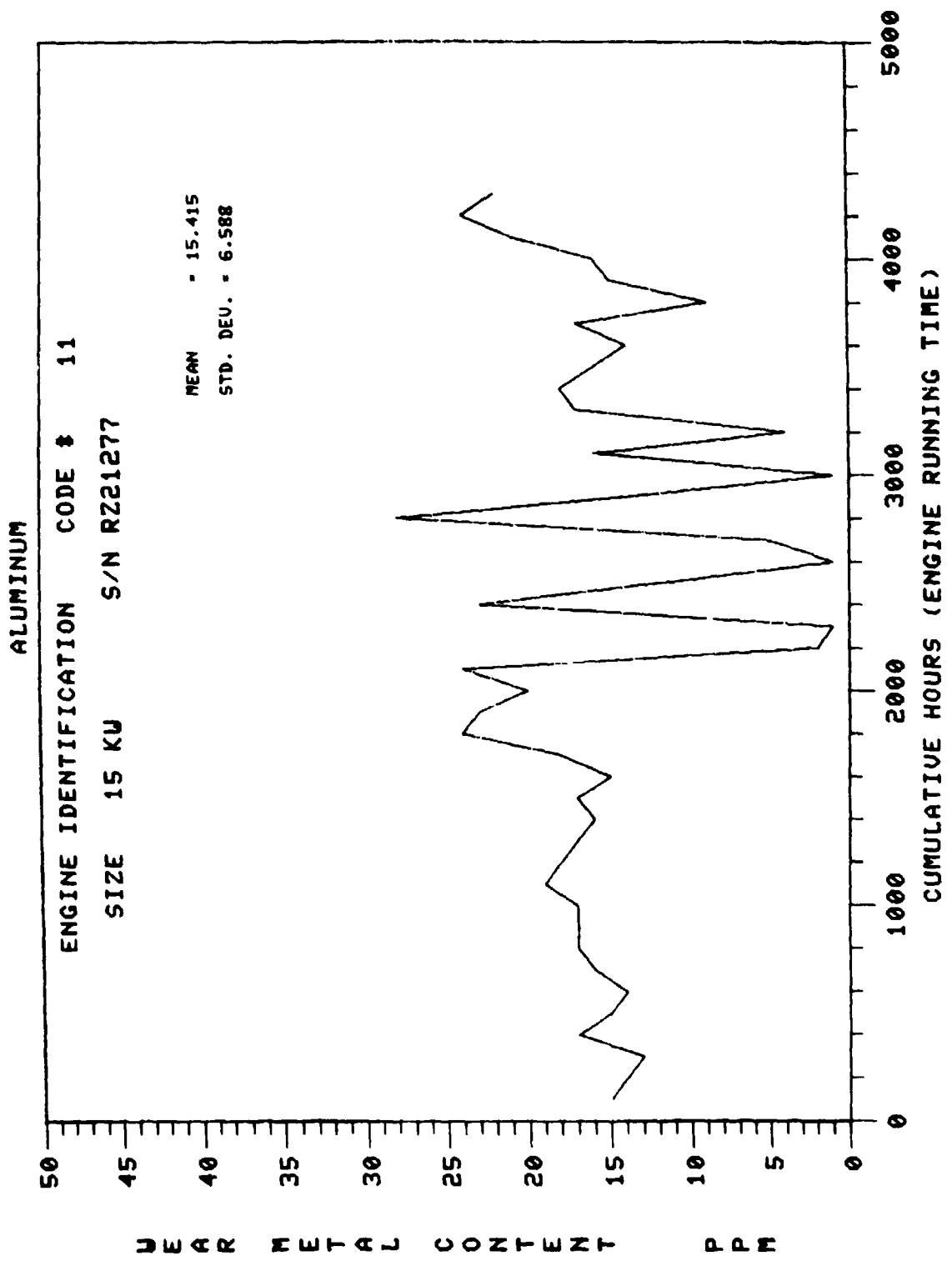
SIZE 15 KW S/N R221277

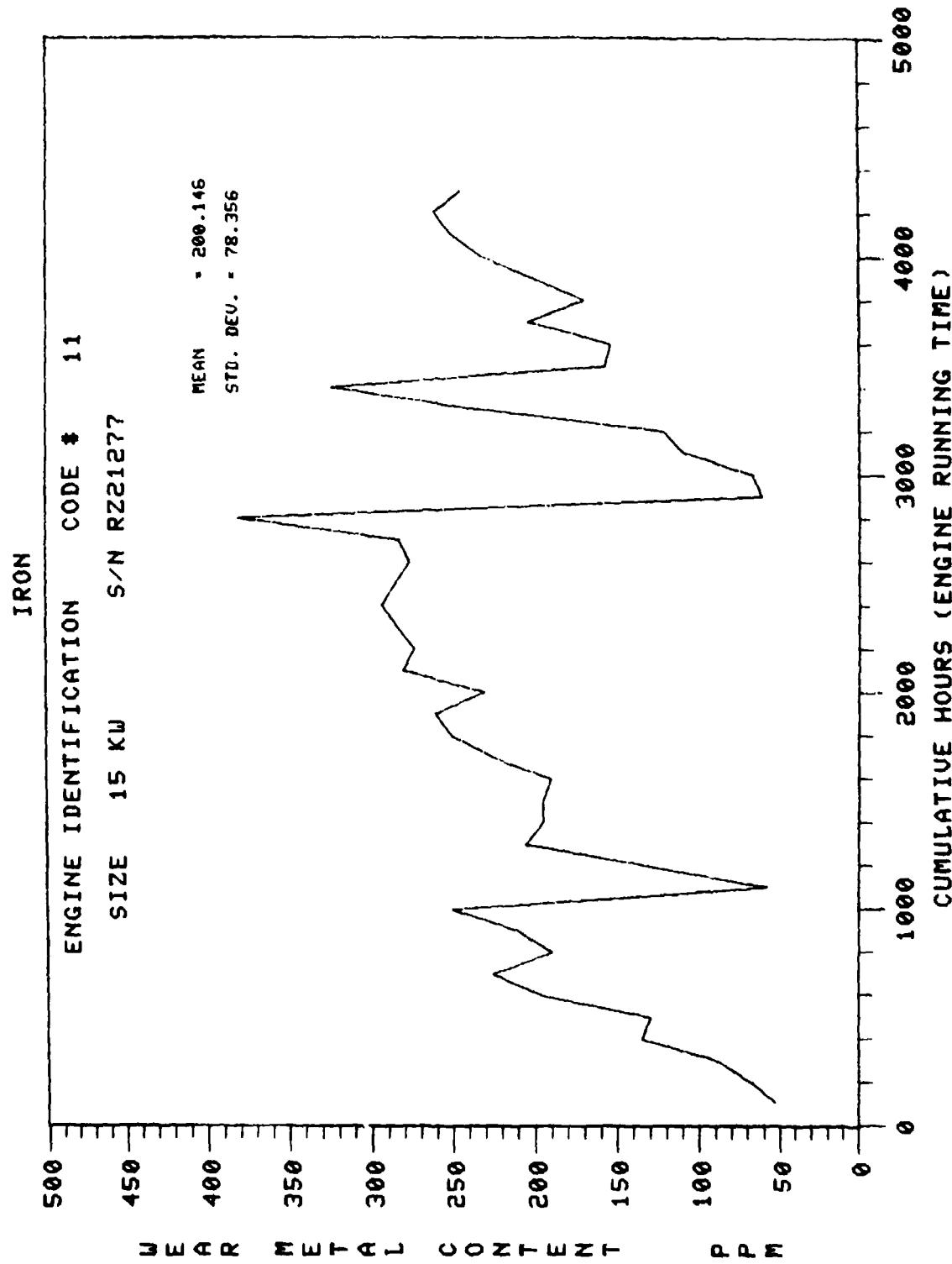
MEAN = 2.256
STD. DEV. = 1.050

T A S E N

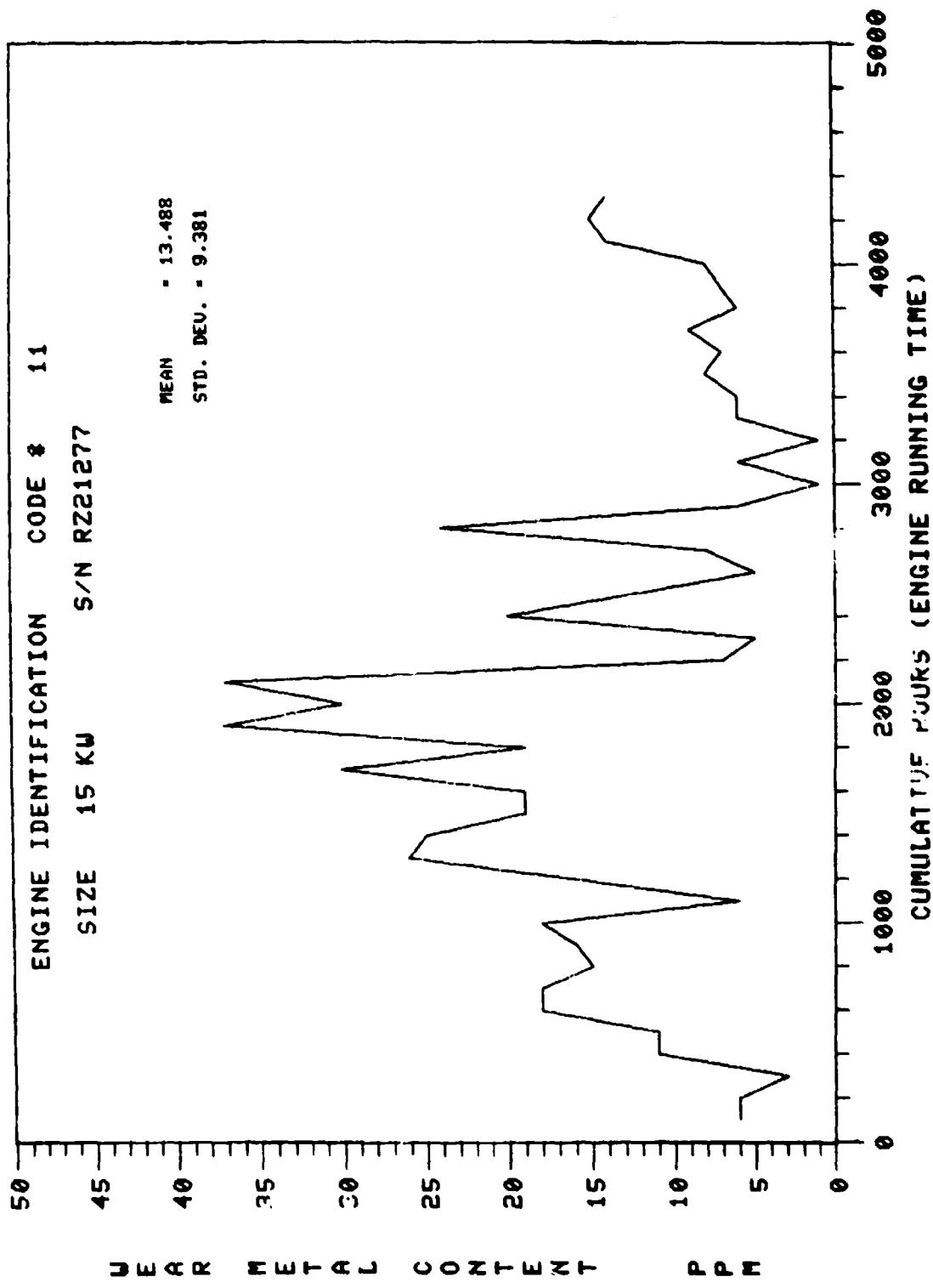
132



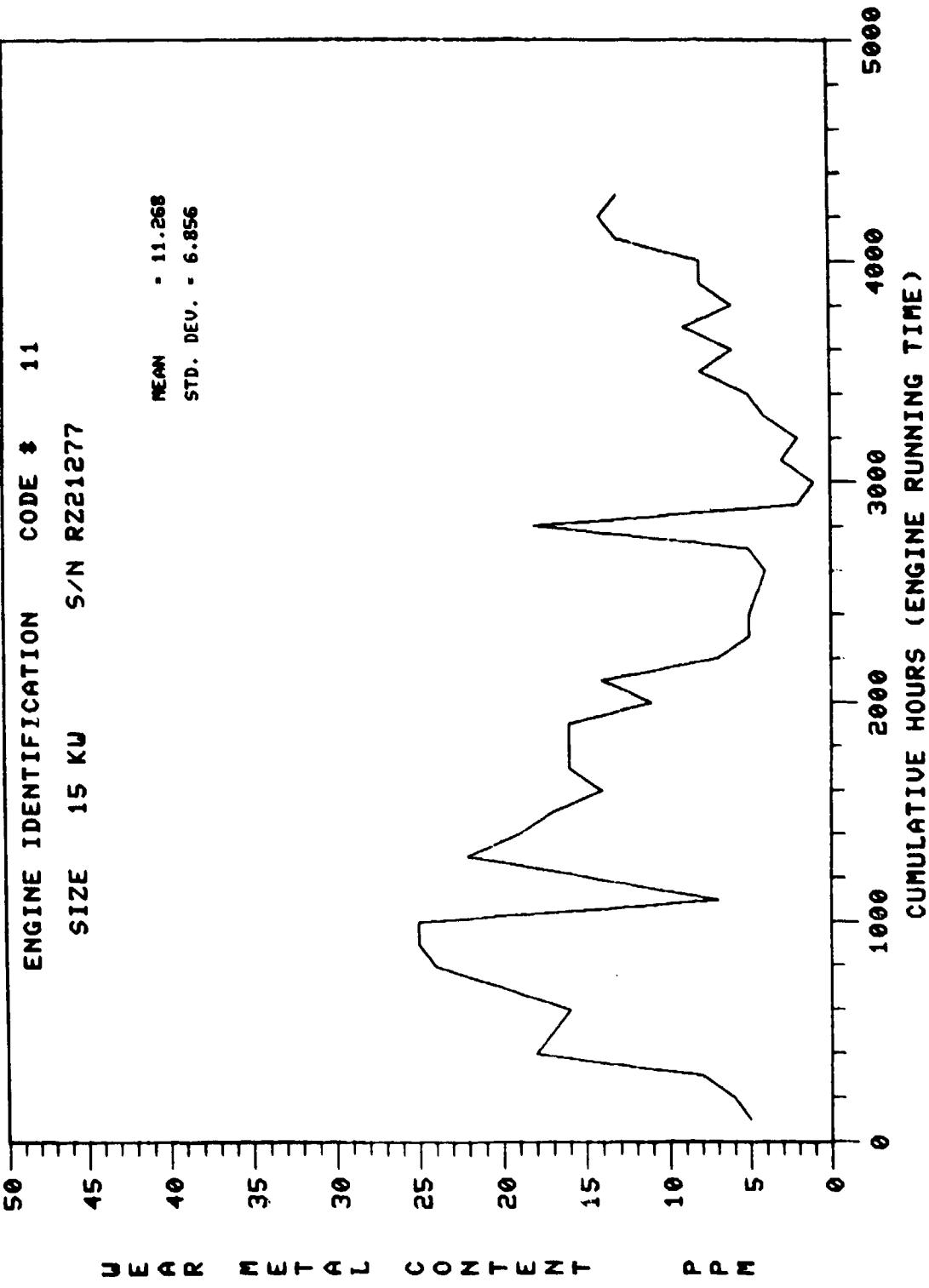


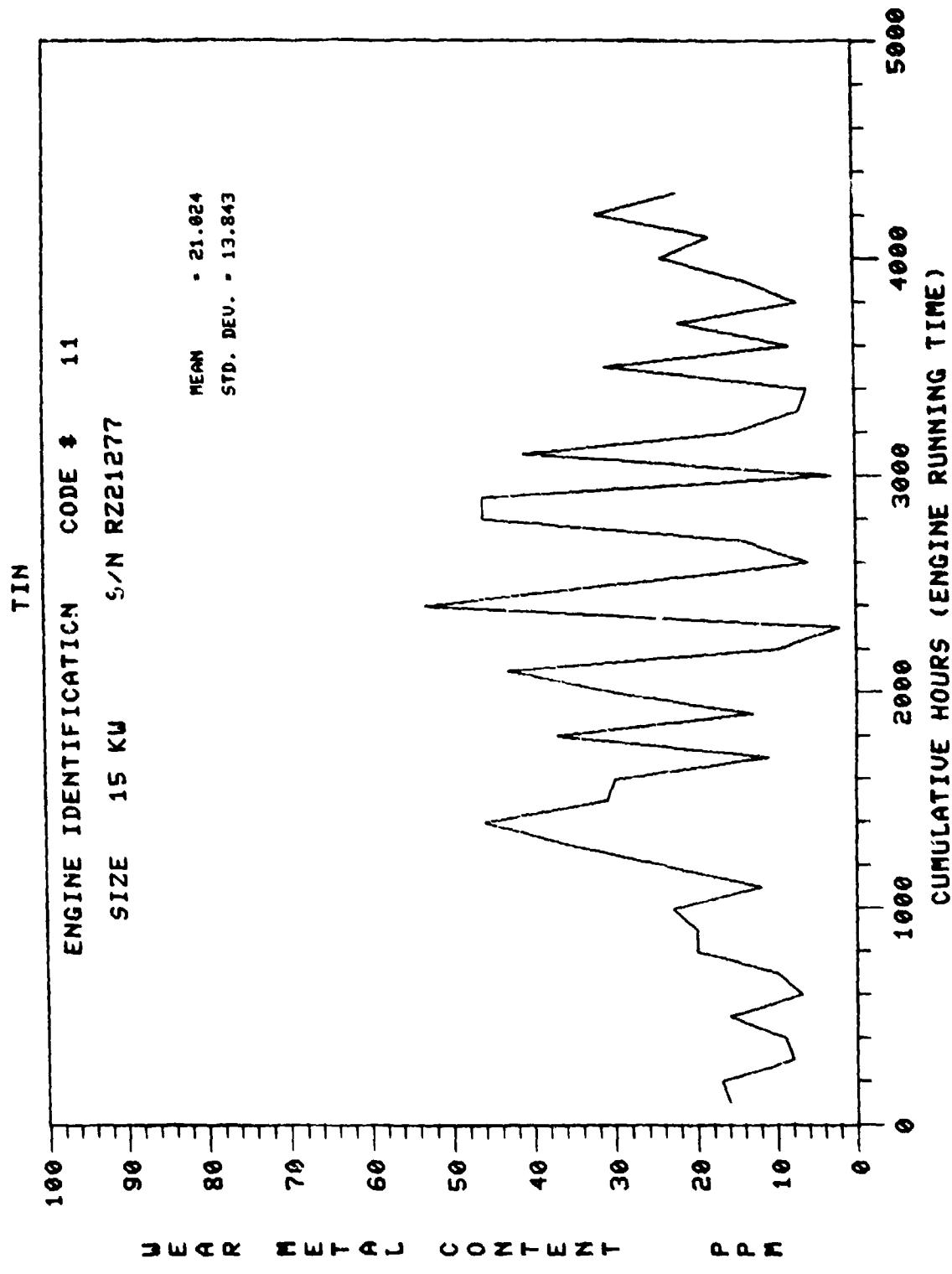


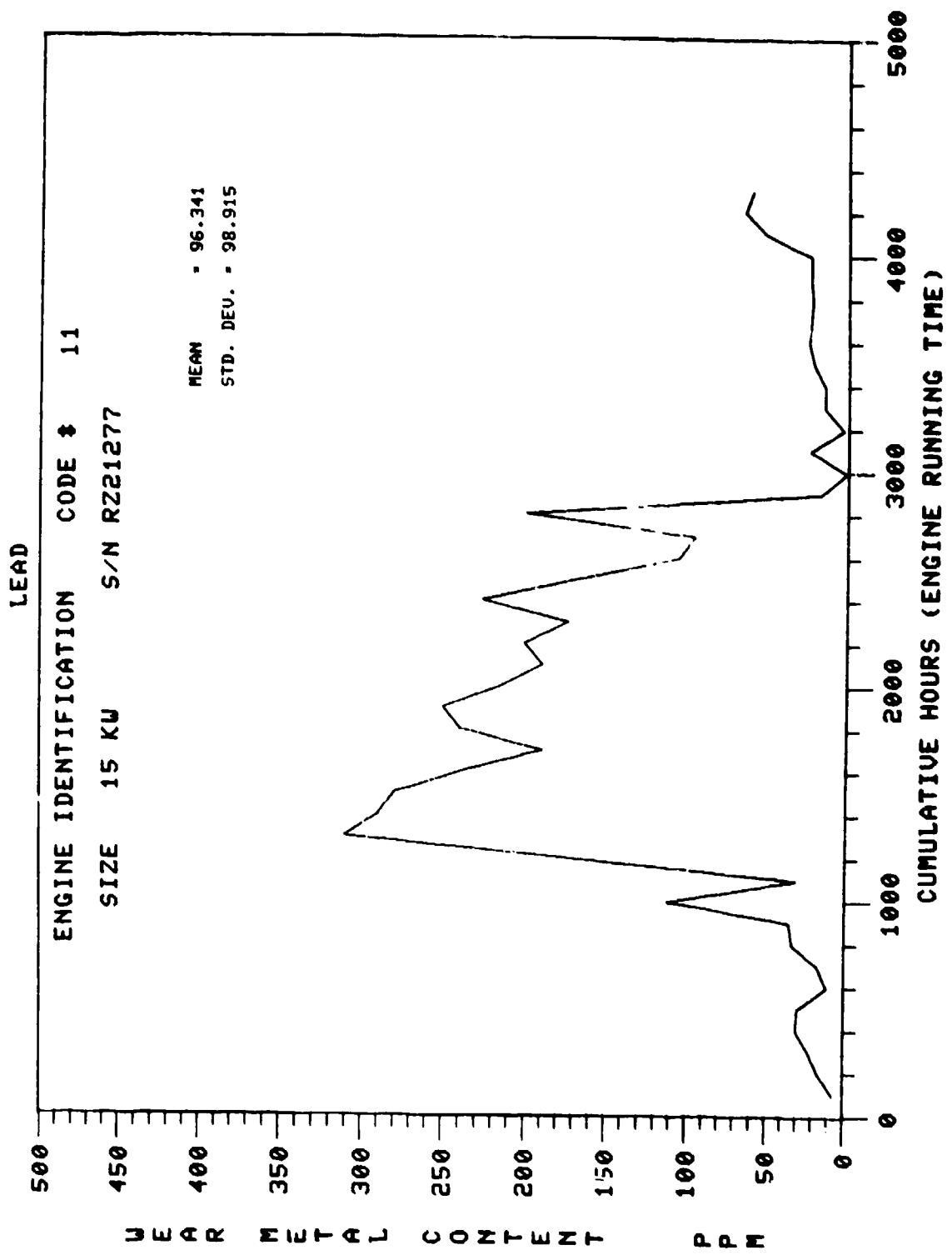
CHROMIUM

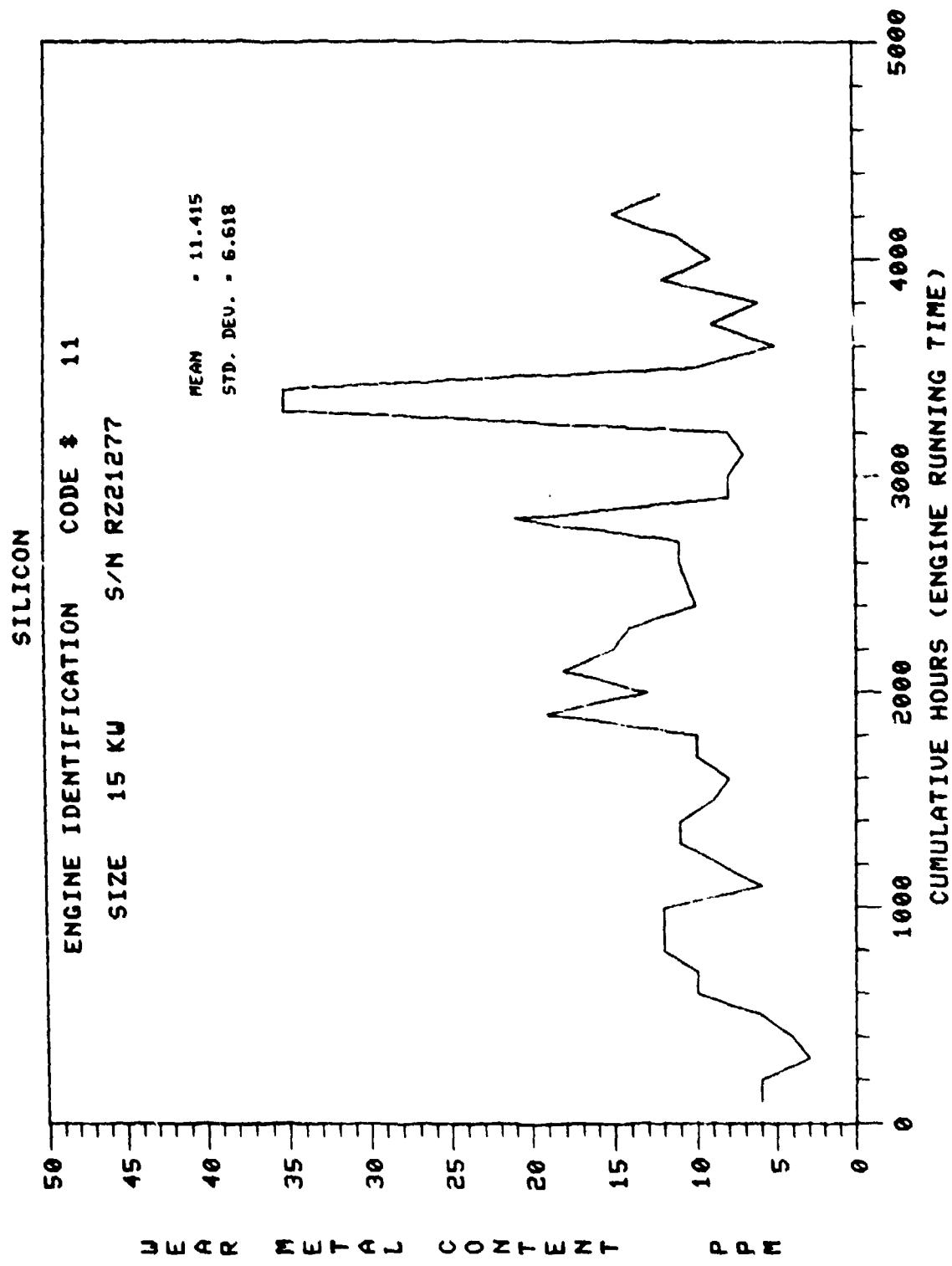


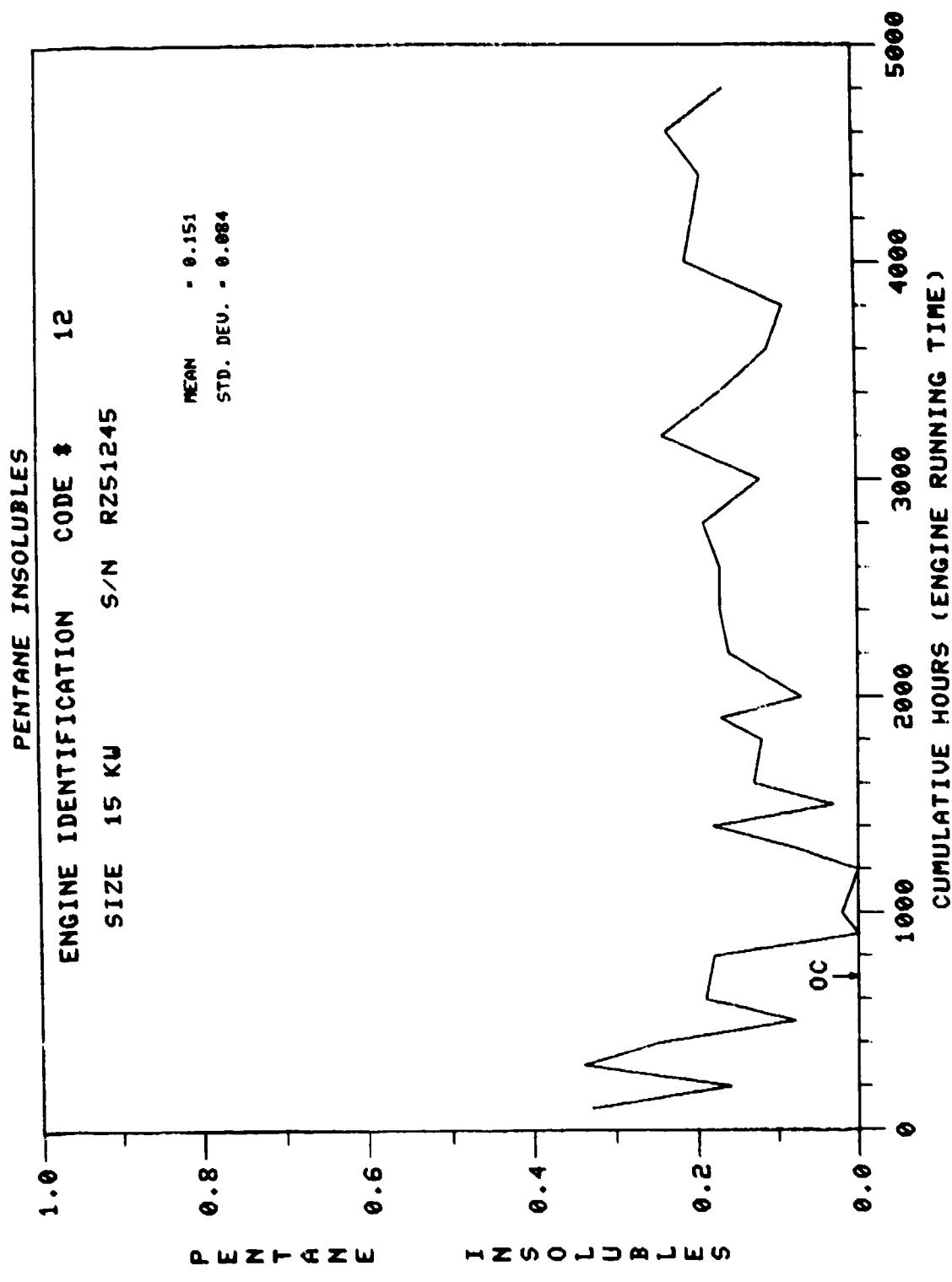
COPPER

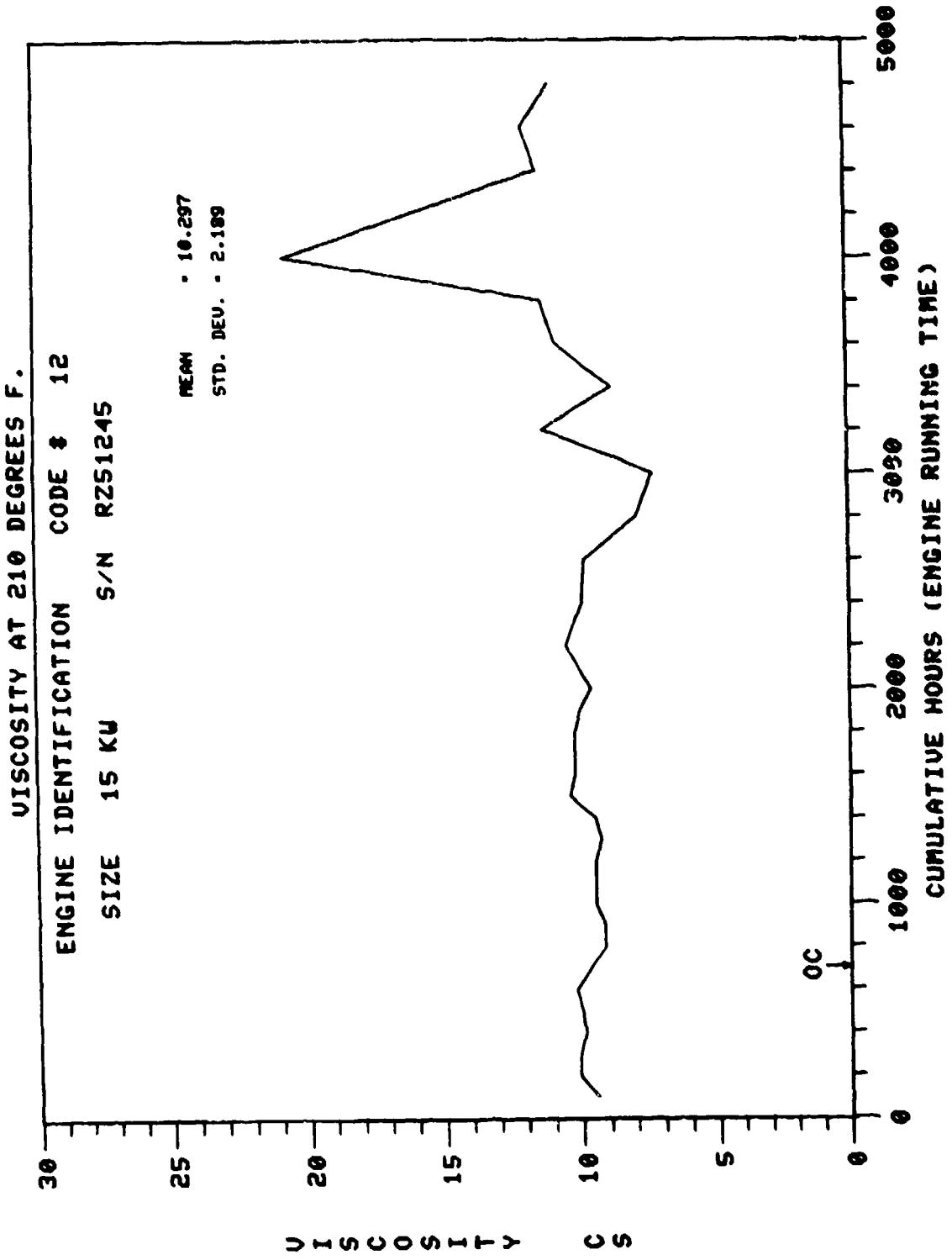










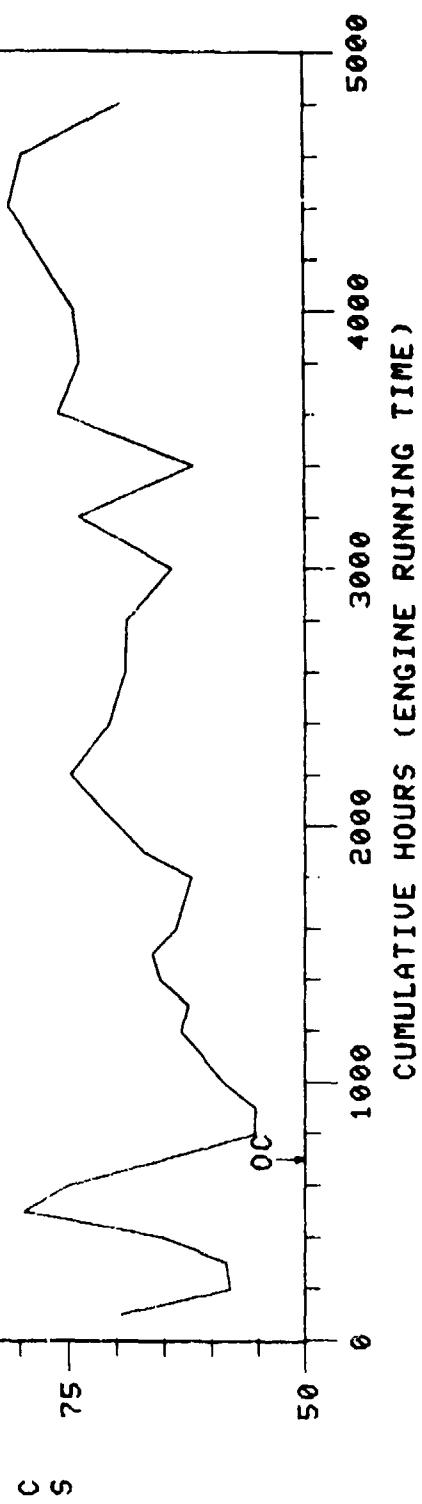


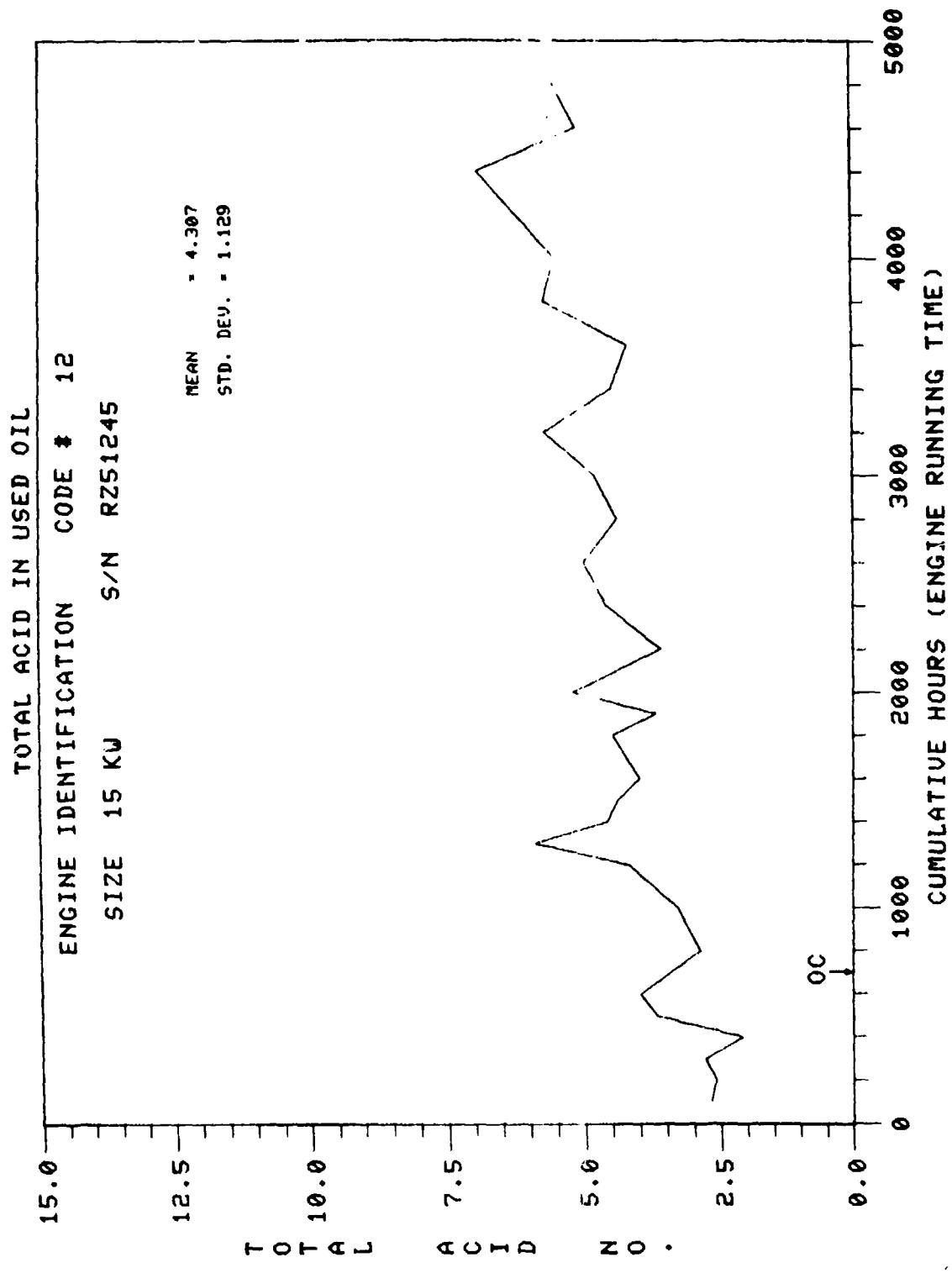
VISCOOSITY AT 100 DEGREES F.

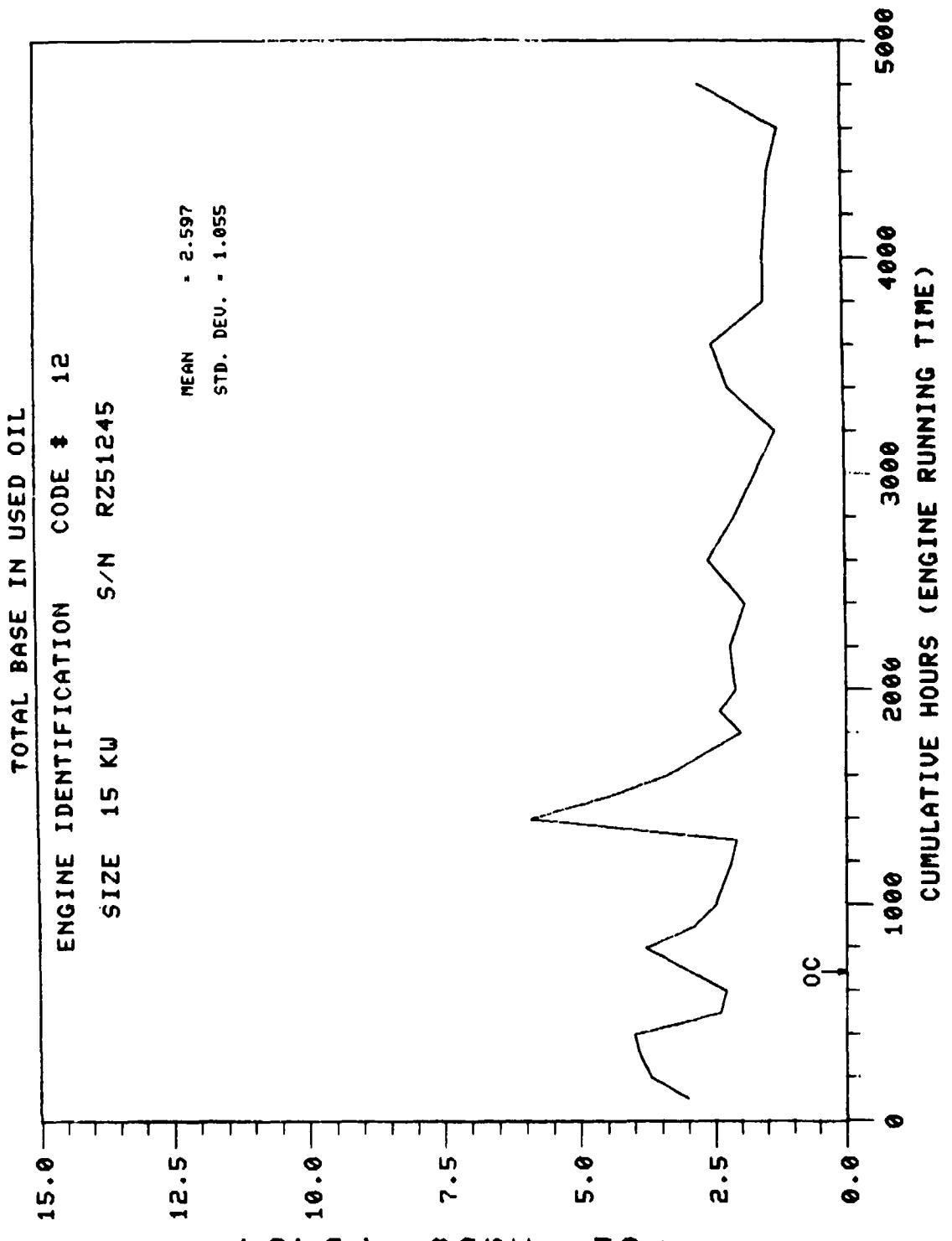
ENGINE IDENTIFICATION CODE # 12
SIZE 15 KU S/N RZ51245

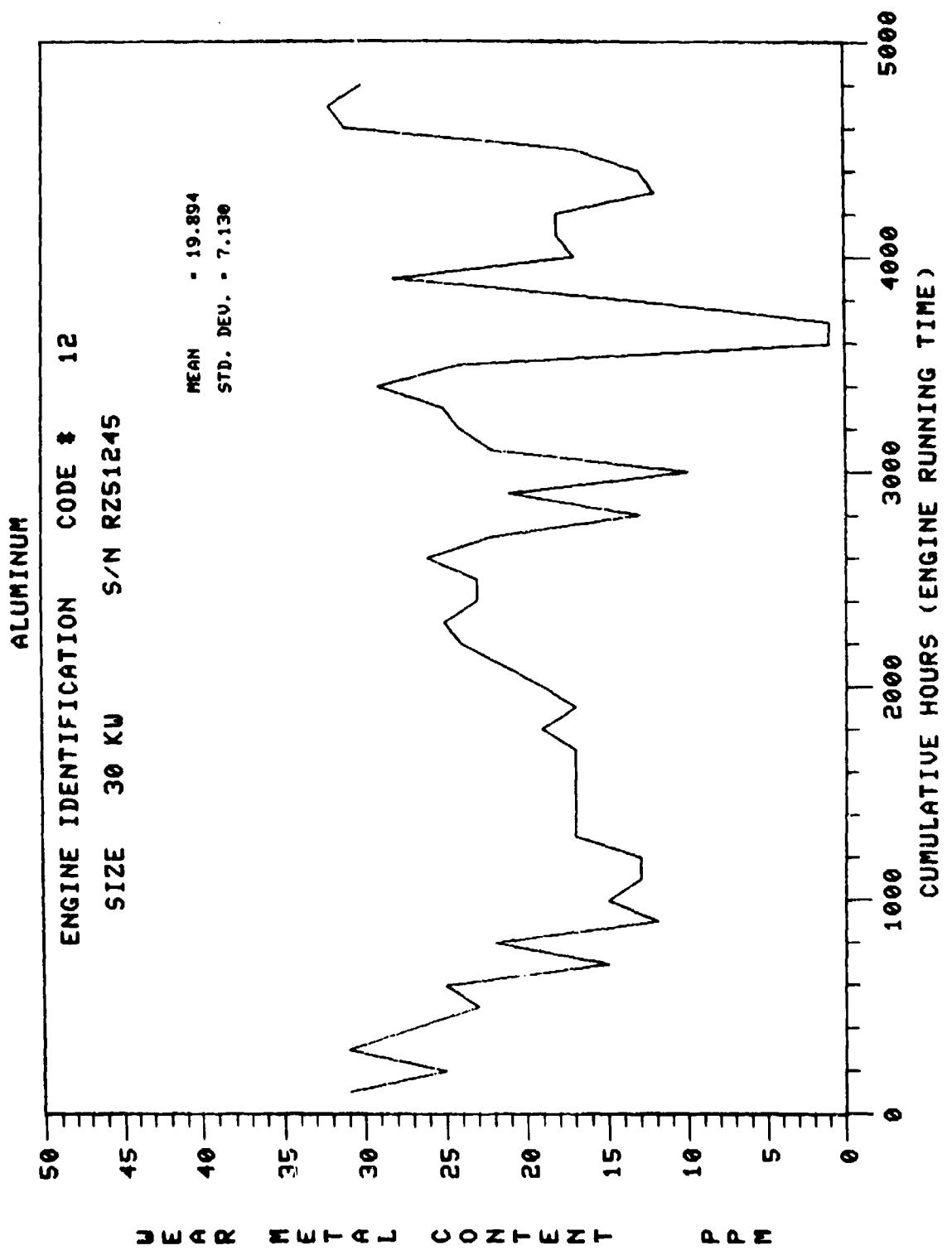
MEAN = 67.717
STD. DEV. = 7.170

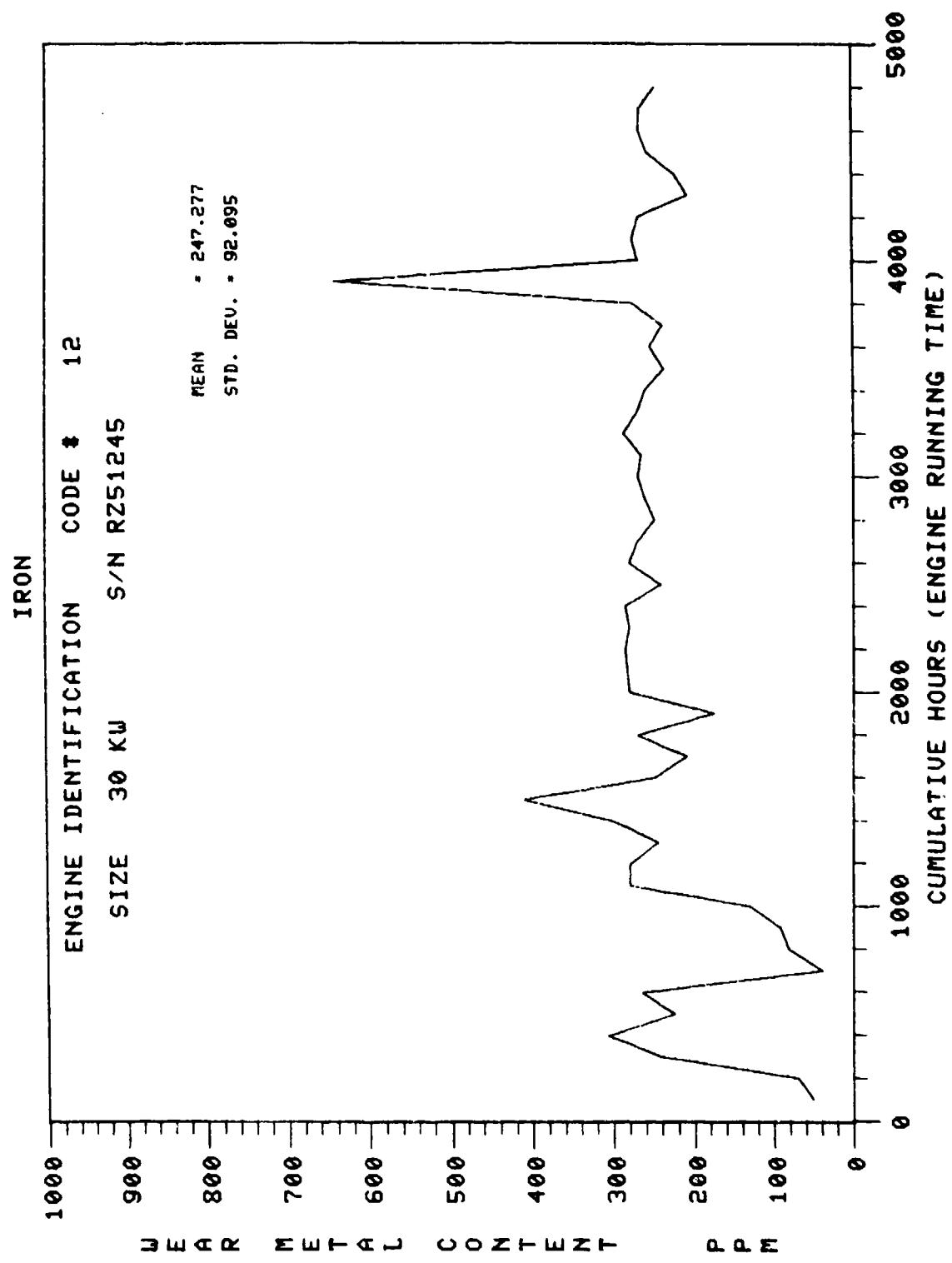
U I S C O S I T Y

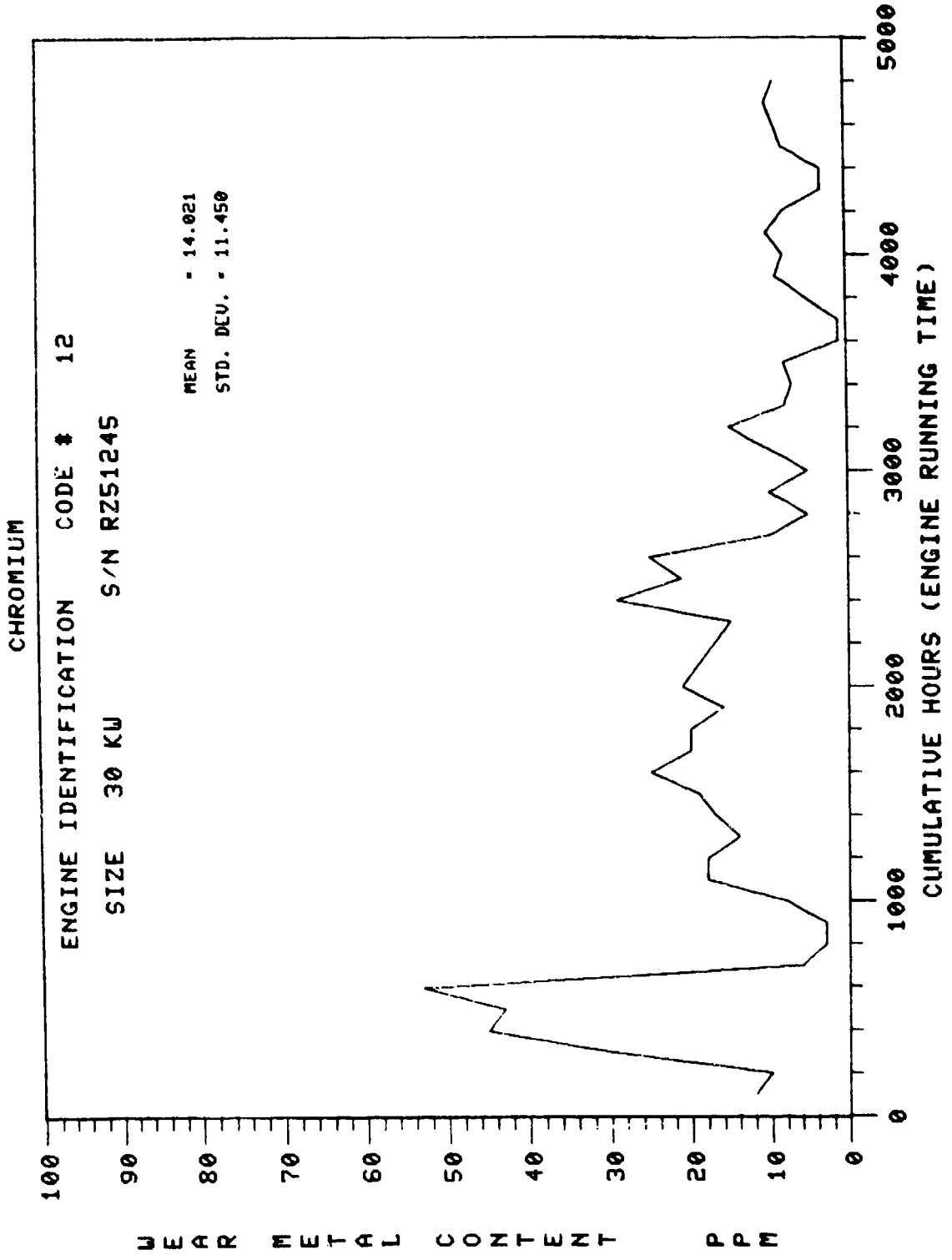


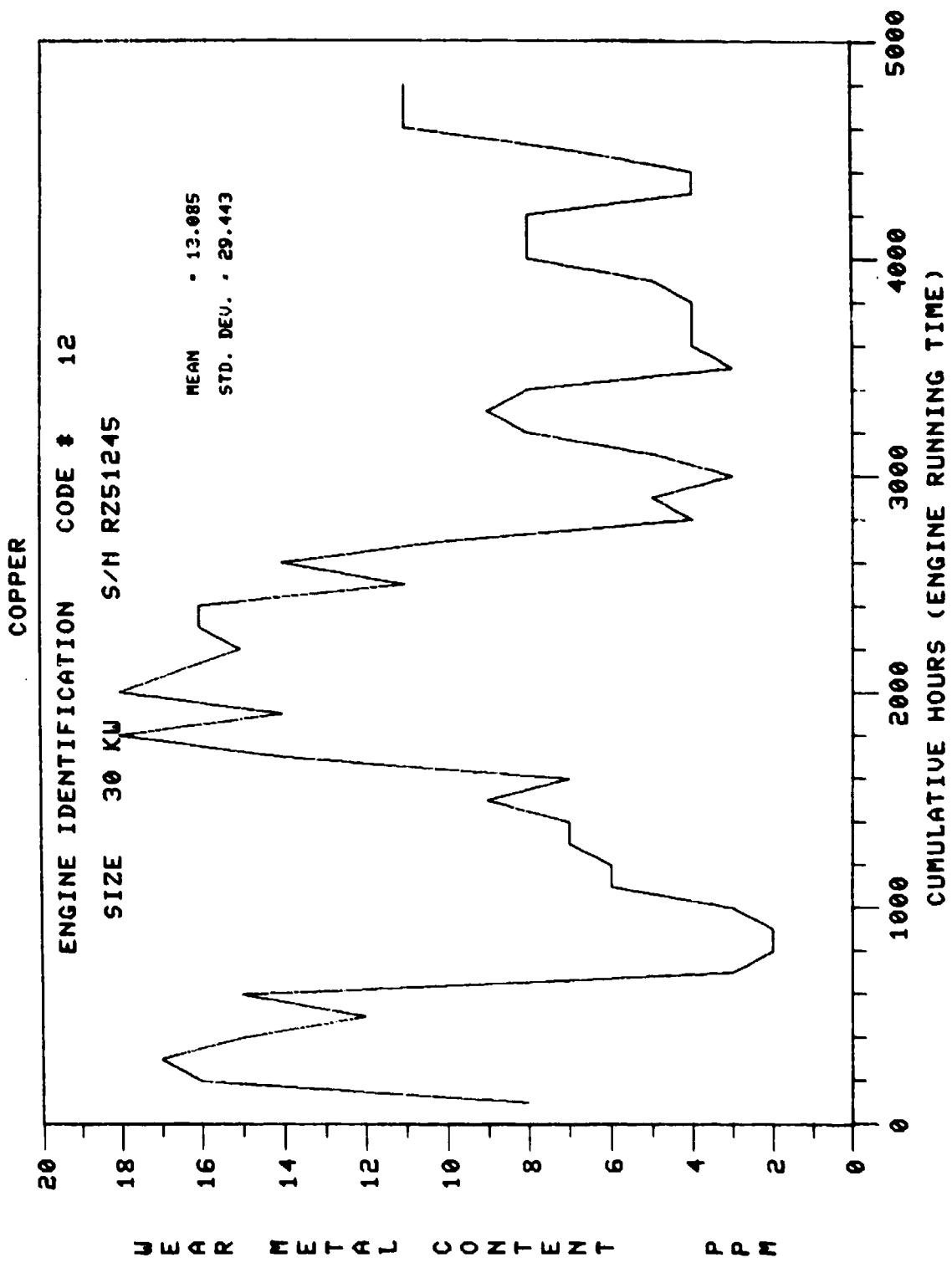


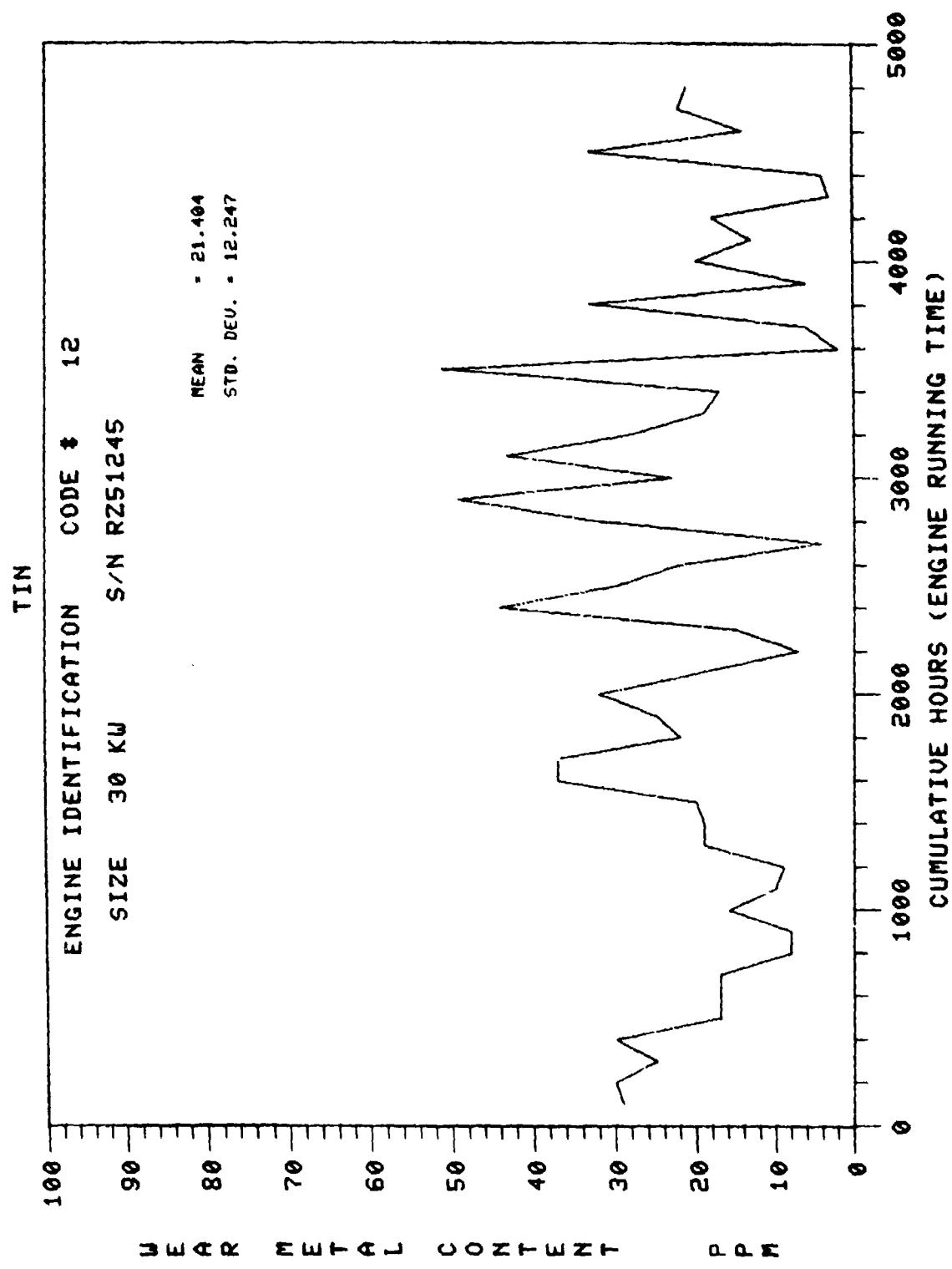


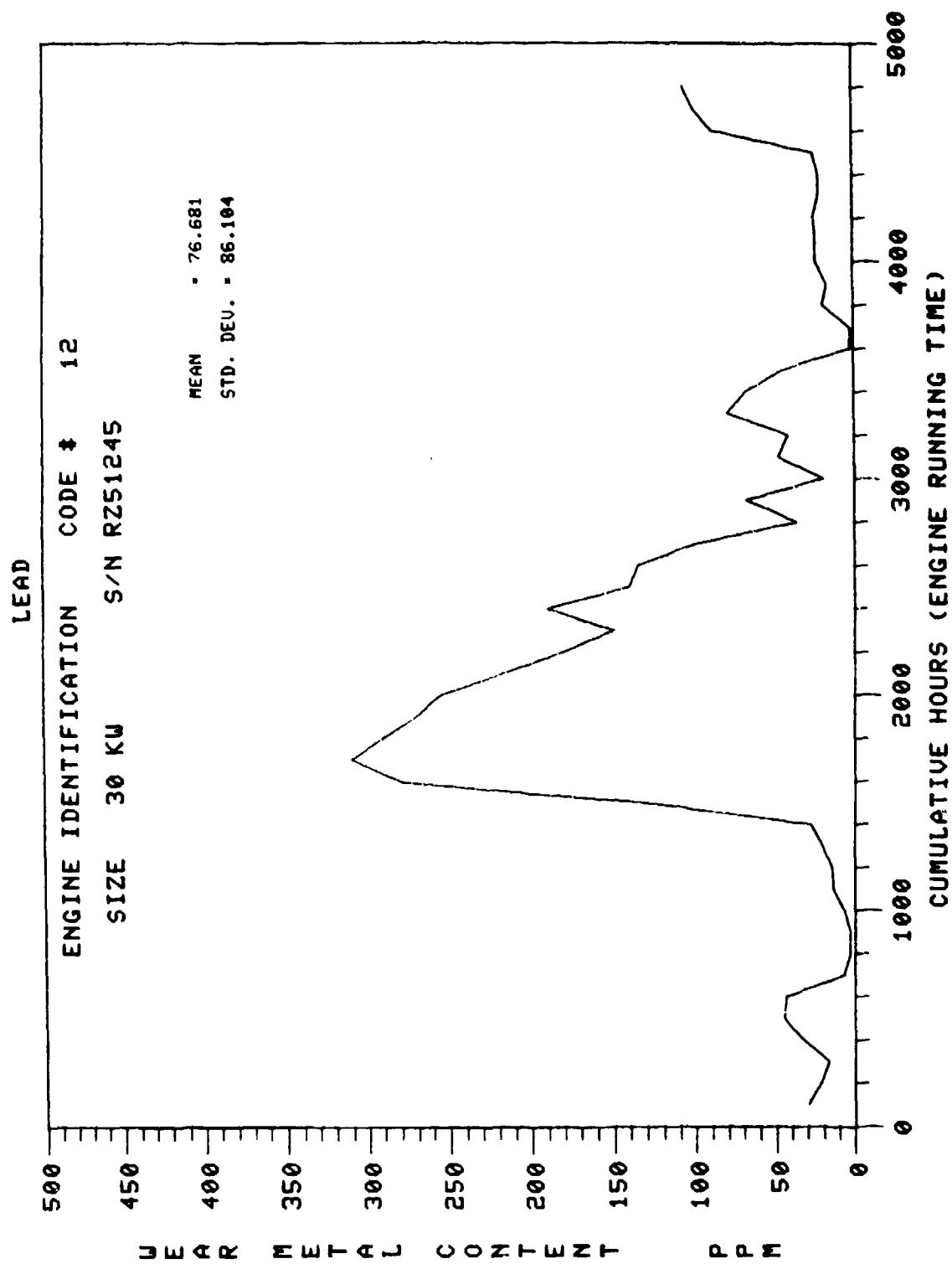


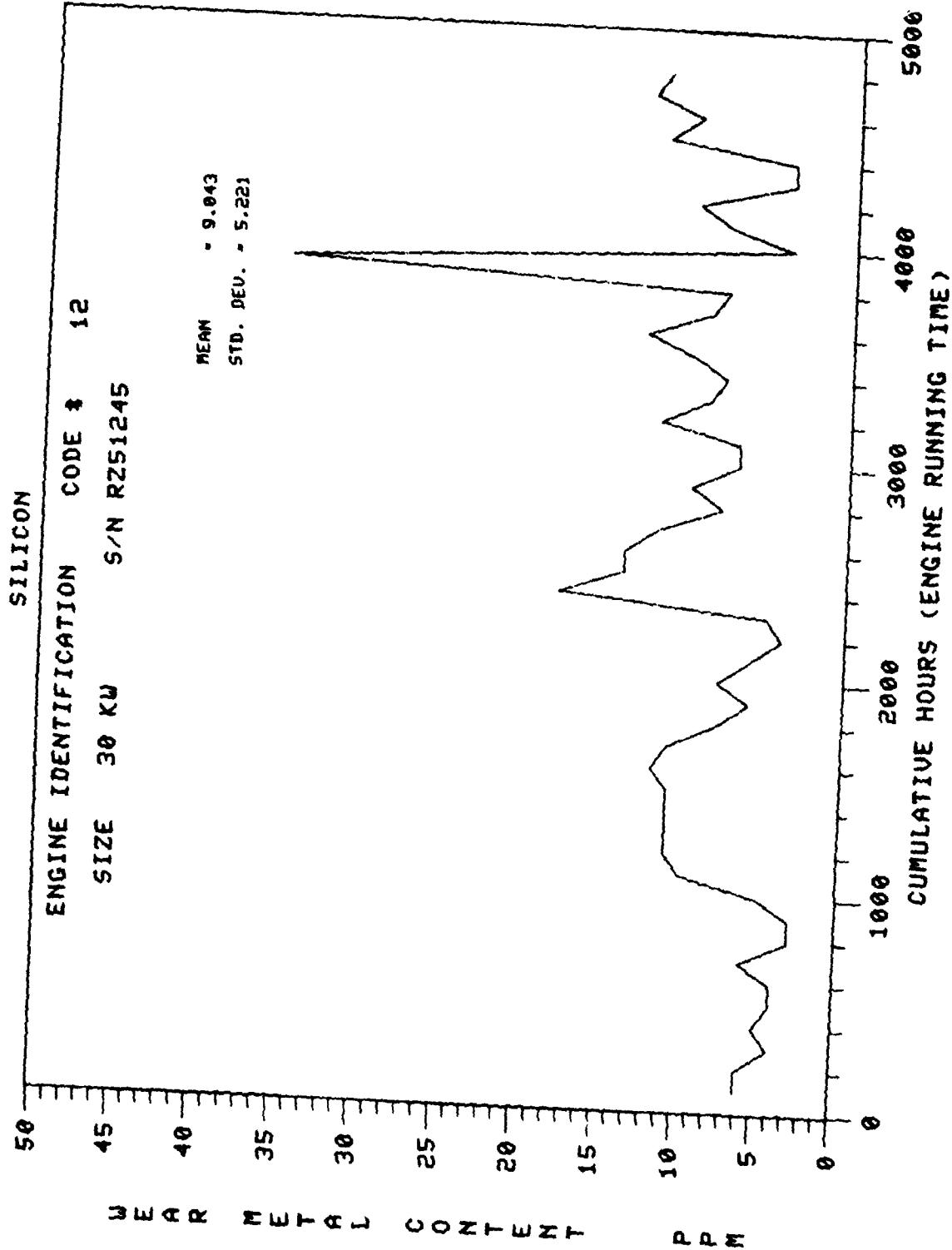












PENTANE INSOLUBLES

ENGINE IDENTIFICATION CODE # 13
SIZE 60 KU S/N F201254

MEAN = 0.141
STD. DEV. = 0.074

PENTANE

152

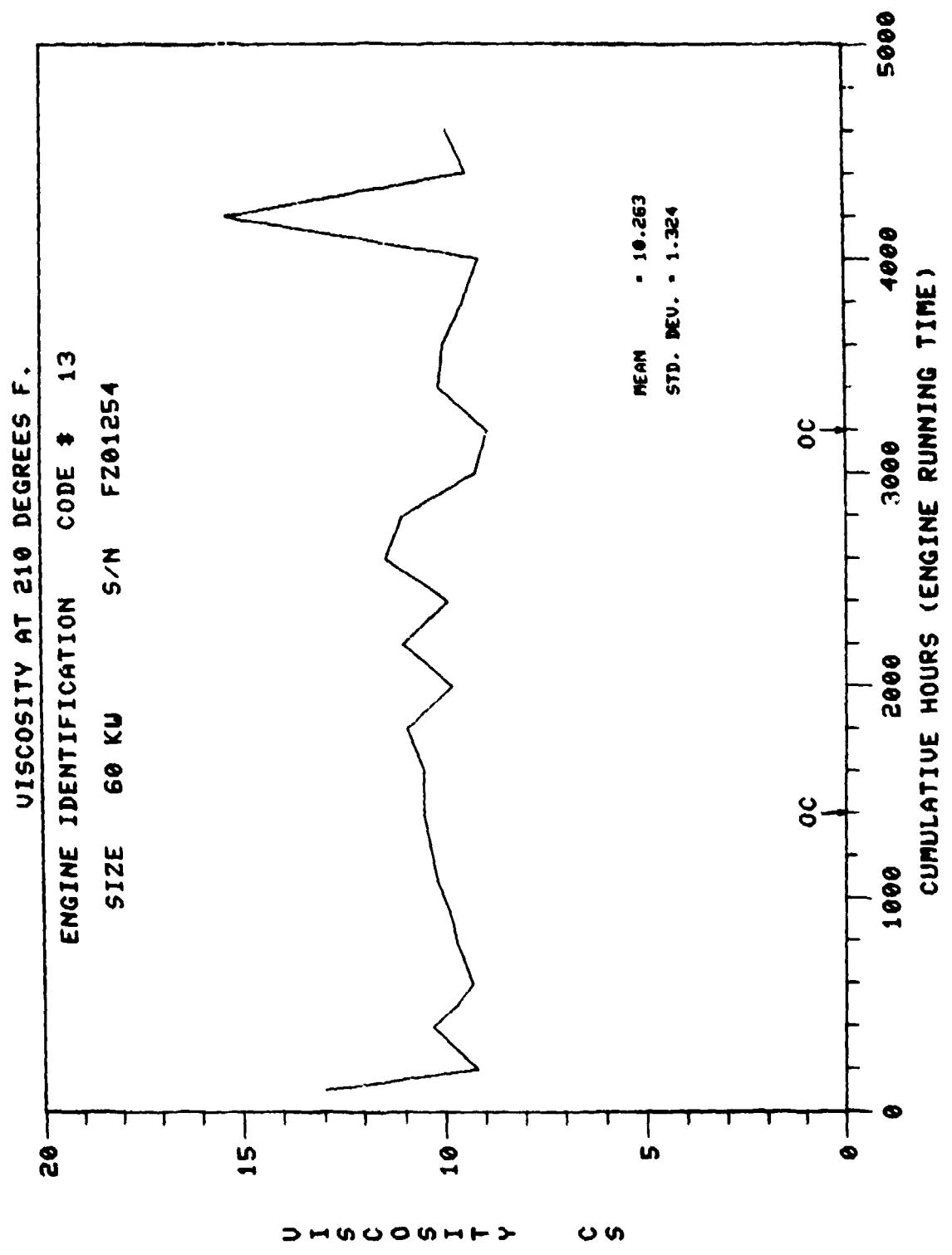
INSOLUBLE

0 1000 2000 3000 4000 5000

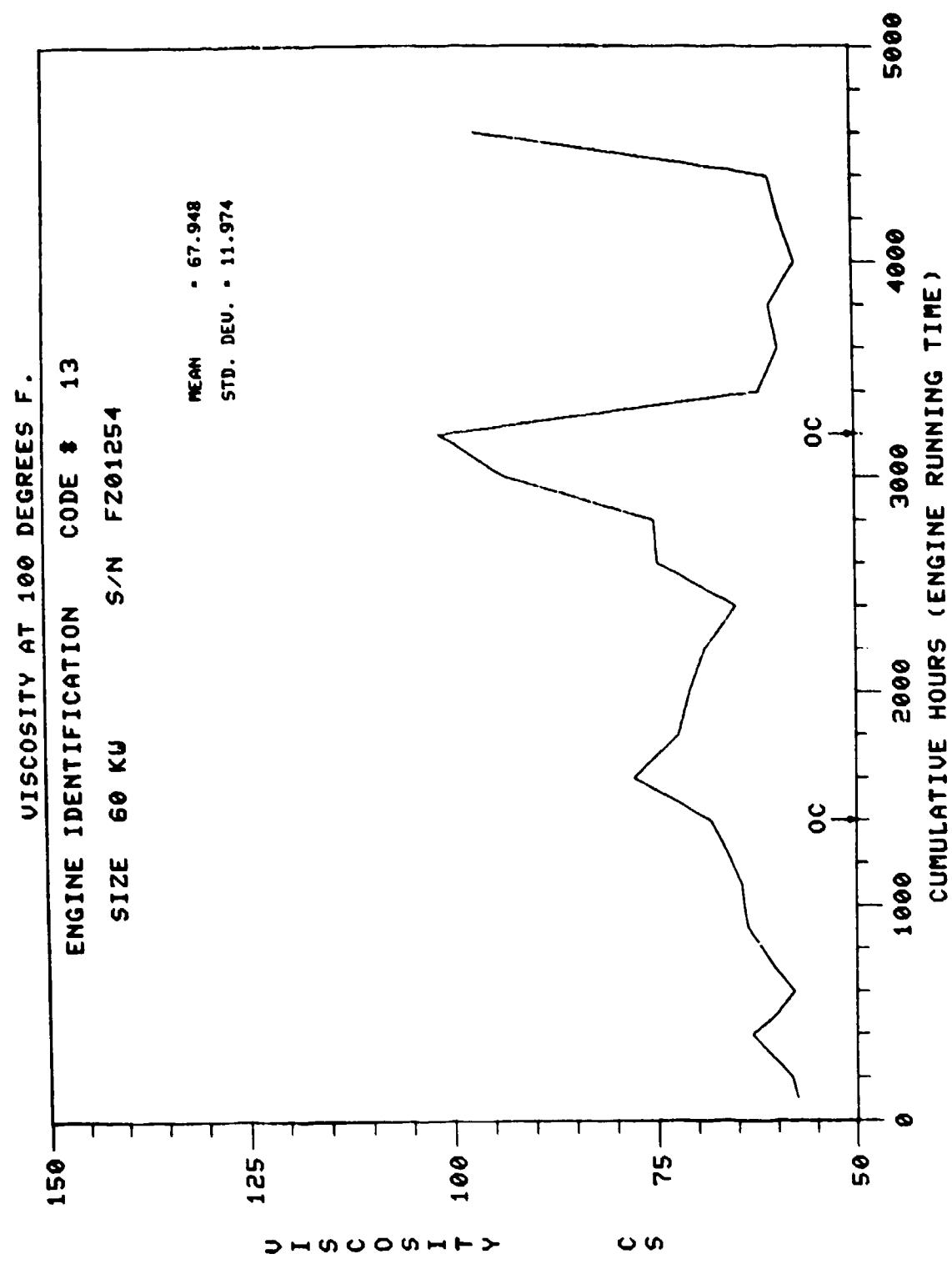
CUMULATIVE HOURS (ENGINE RUNNING TIME)

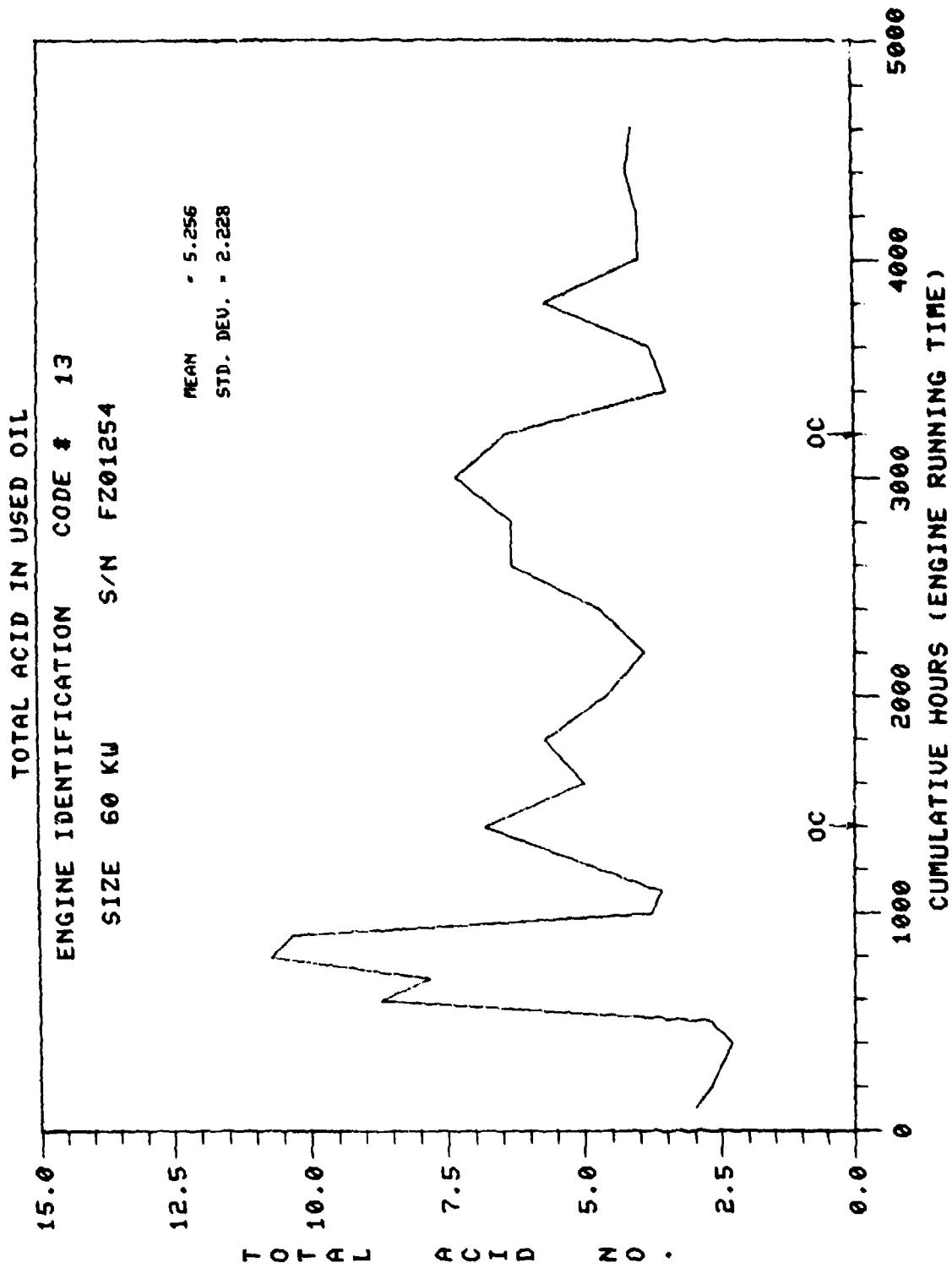
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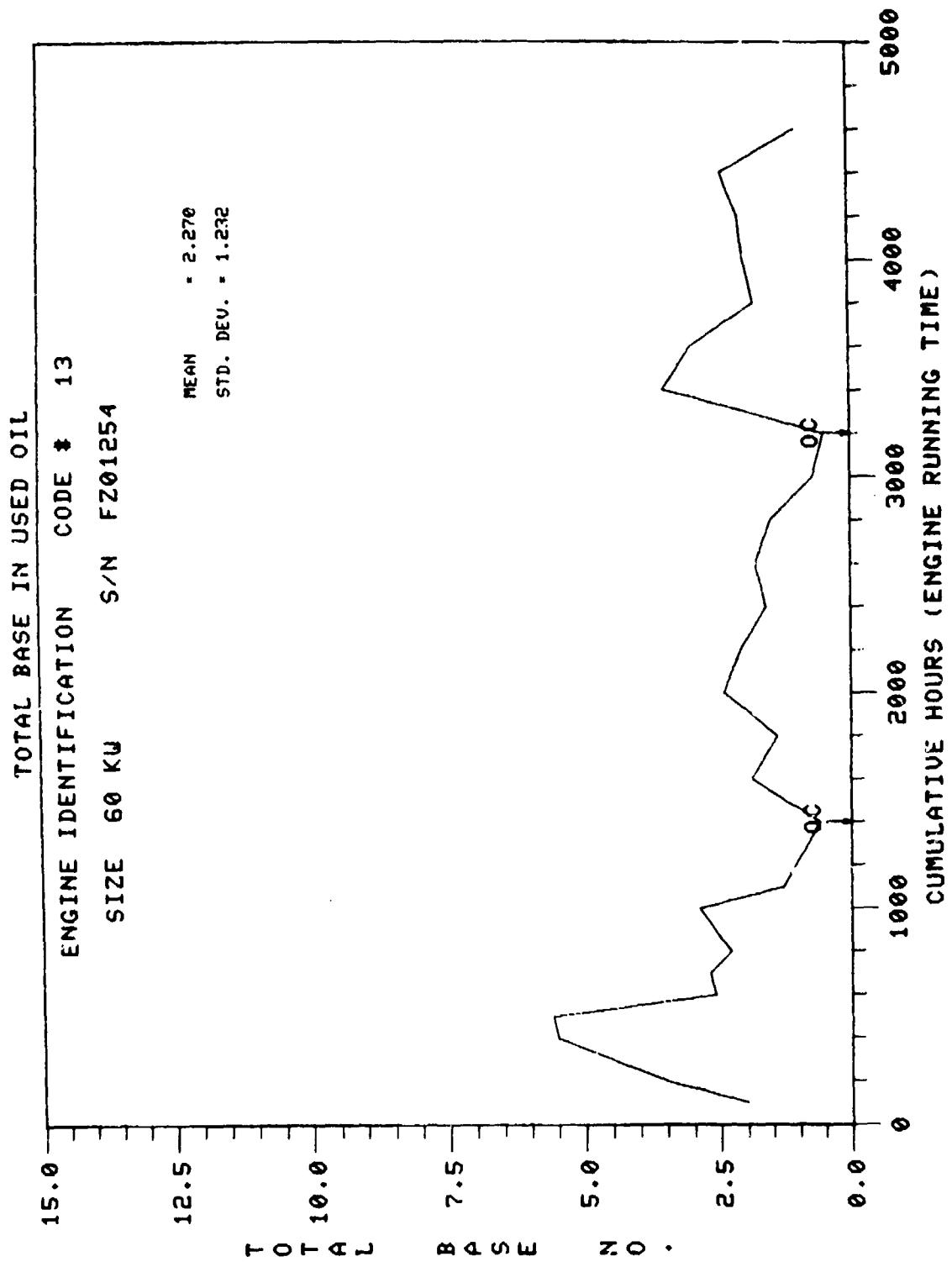
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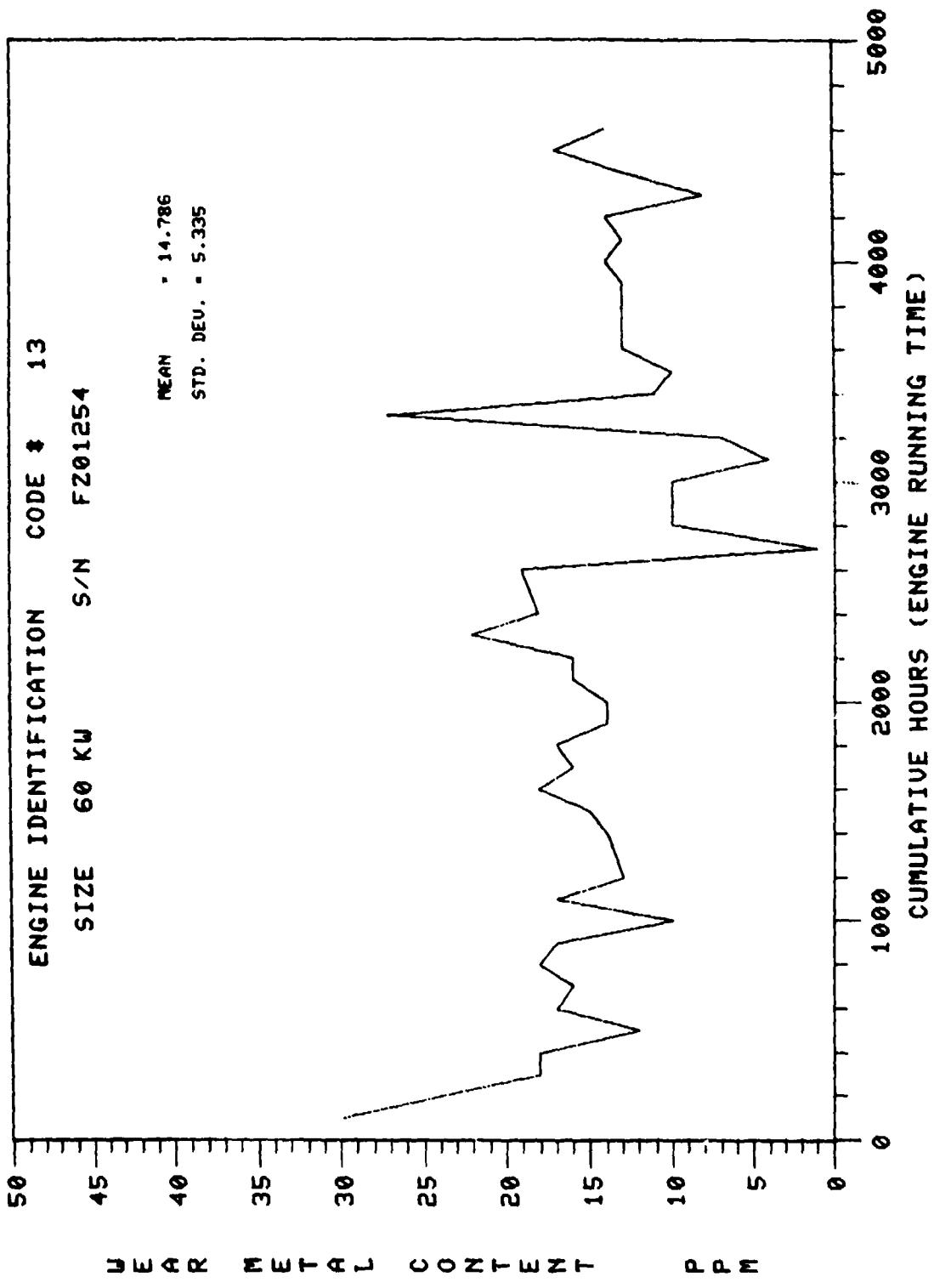
D I S C O S I T Y C S



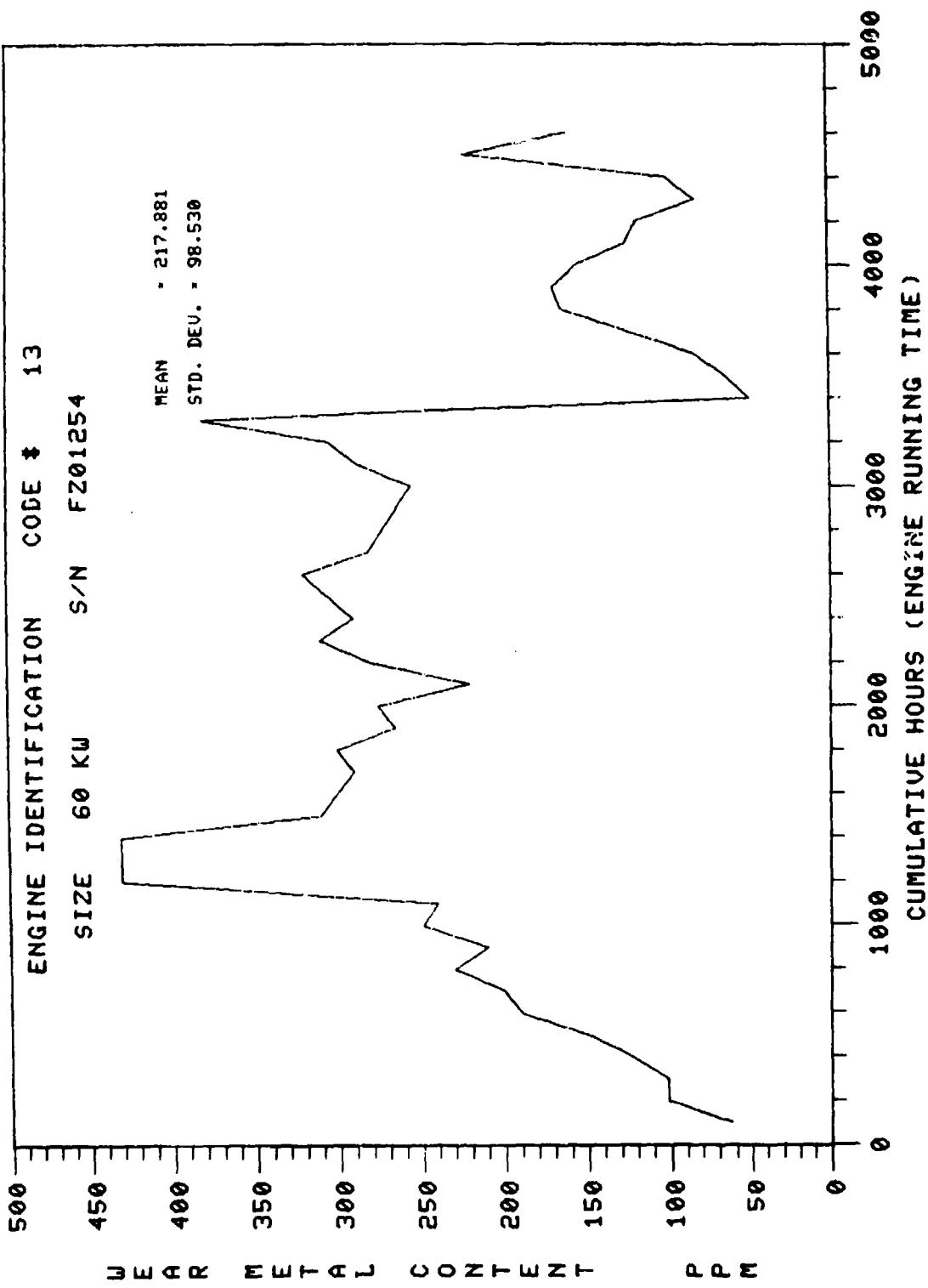




ALUMINUM



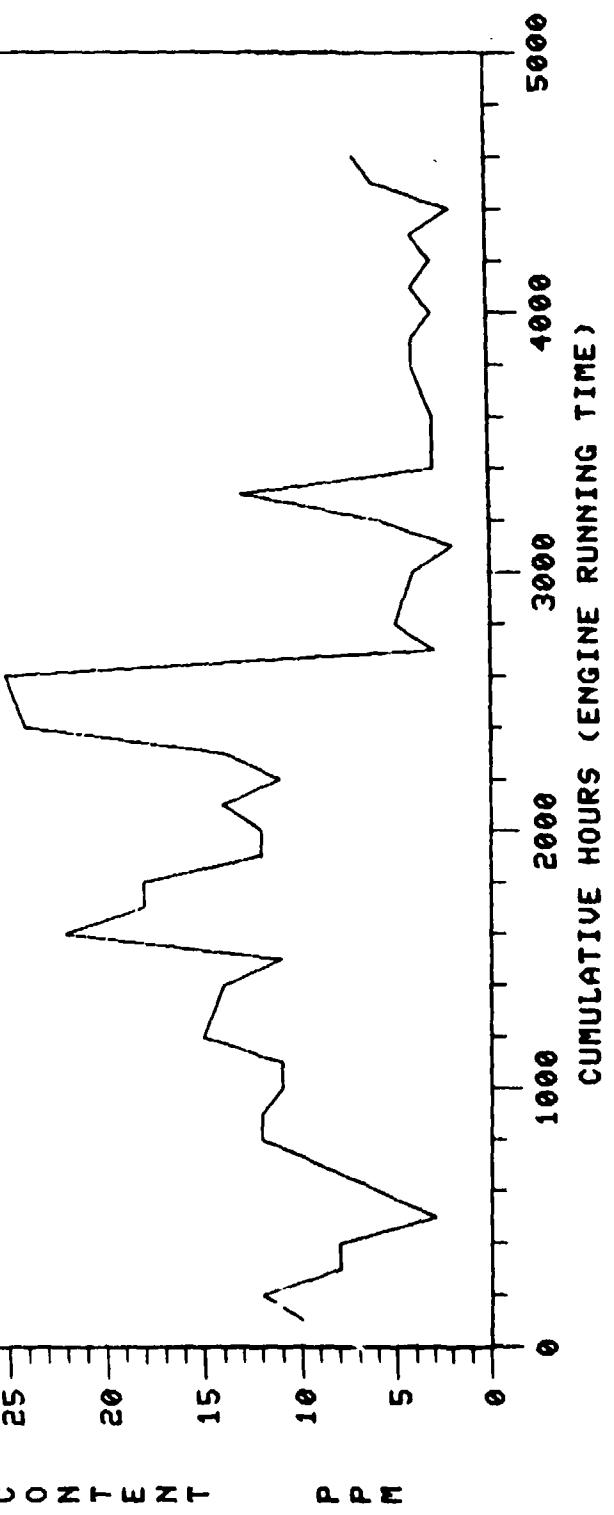
IRON



CHROMIUM

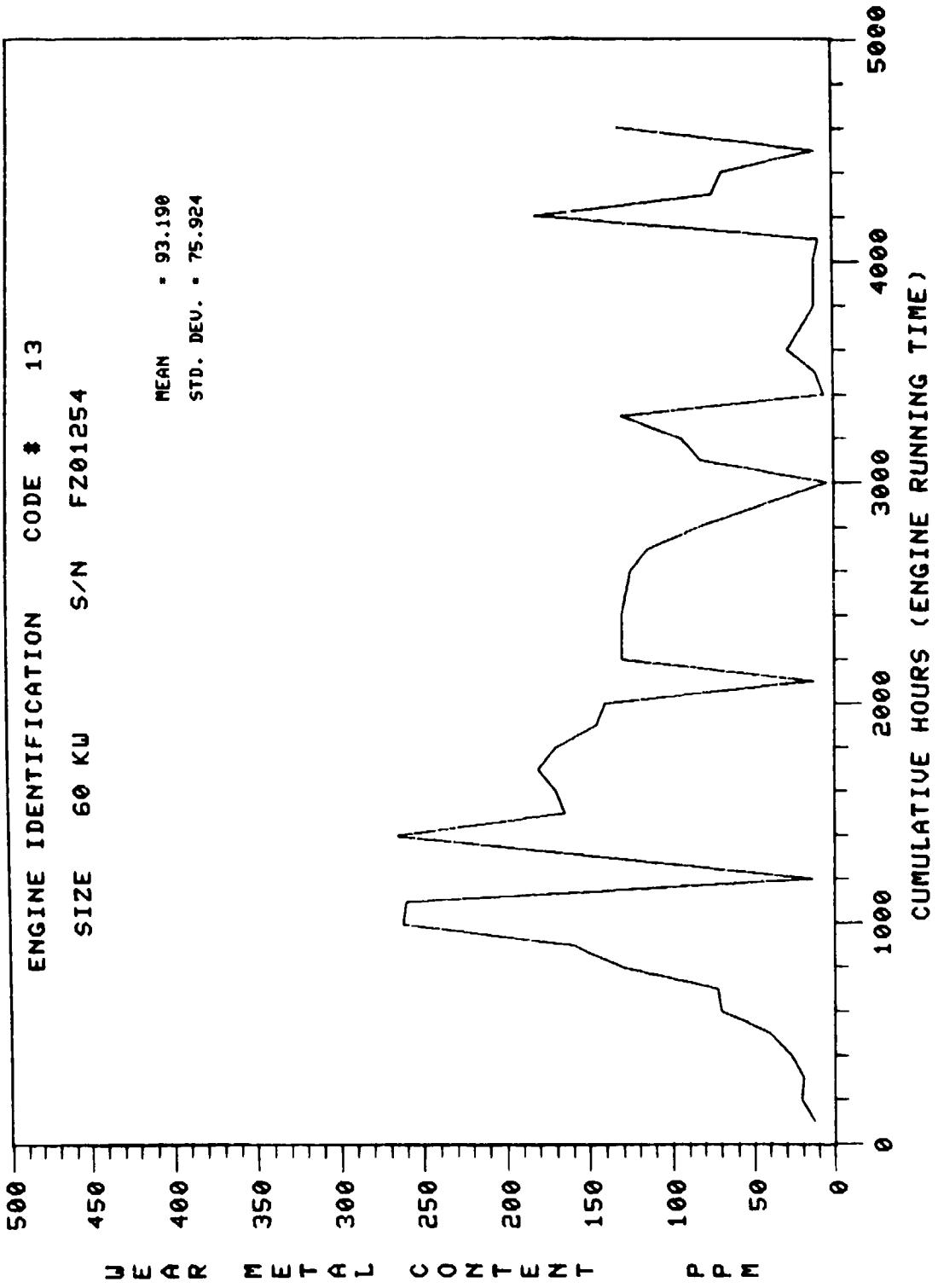
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SIZE 60 KW S/N FZ01254

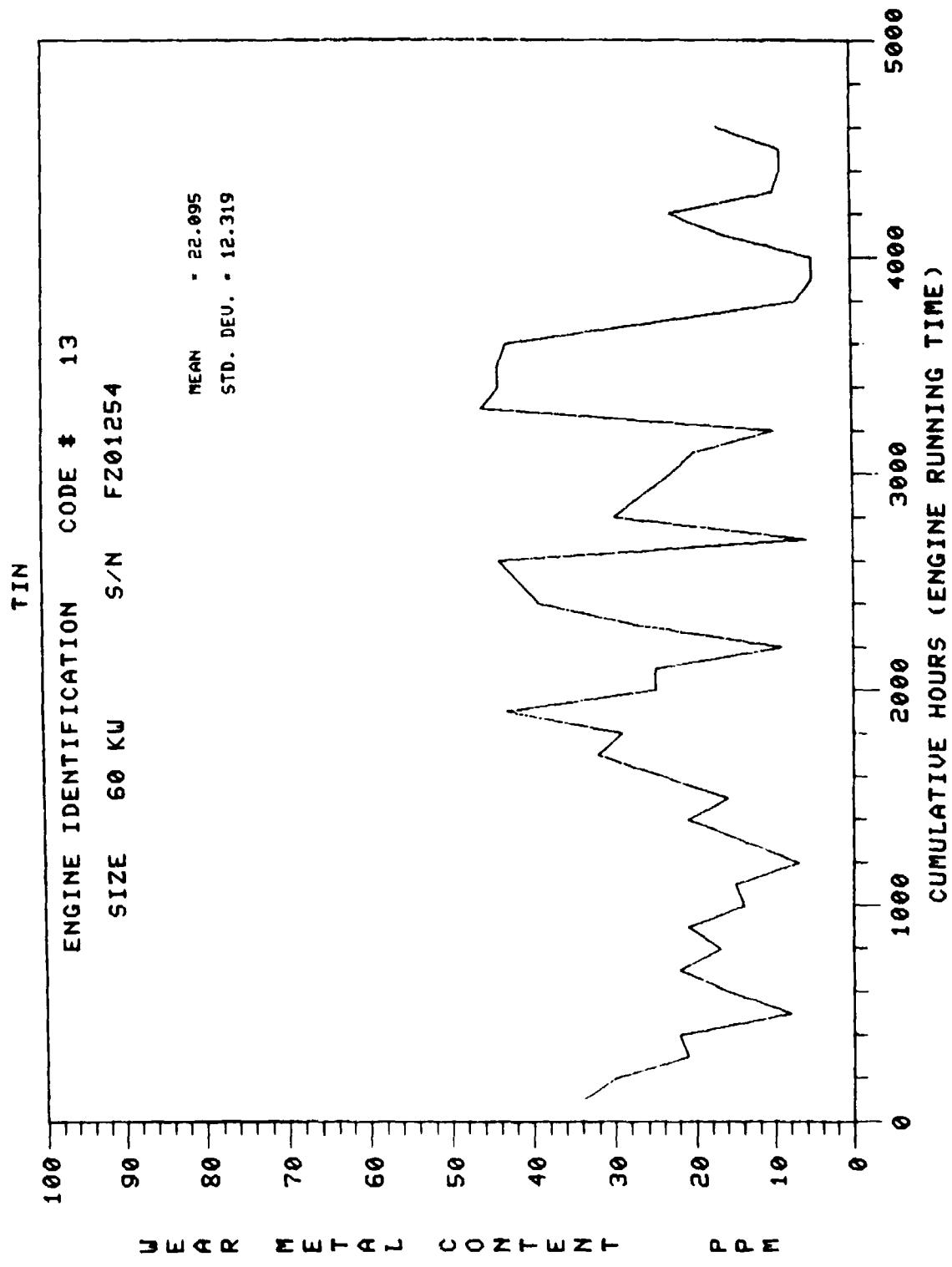
MEAN = 9.310
STD. DEV. = 6.091

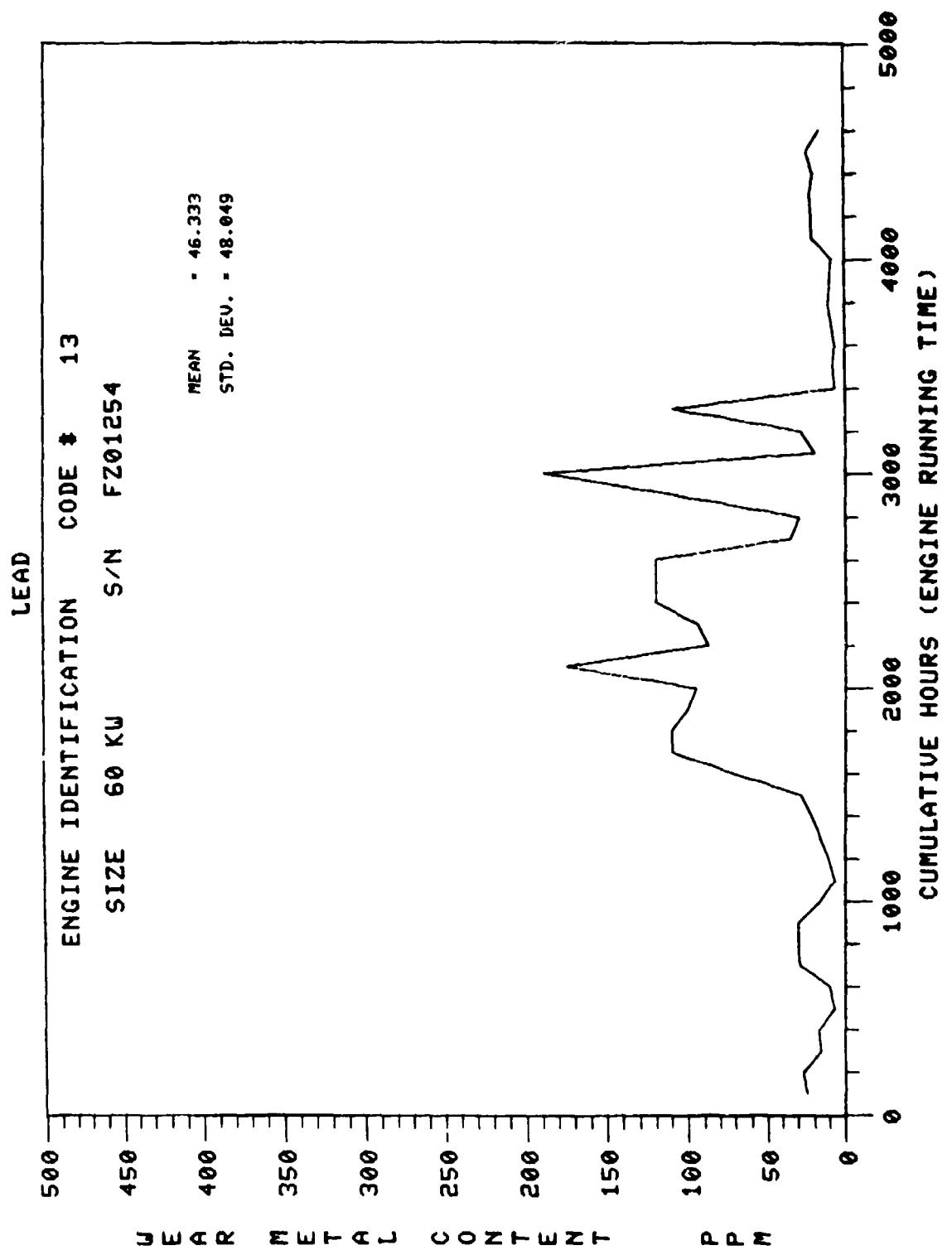


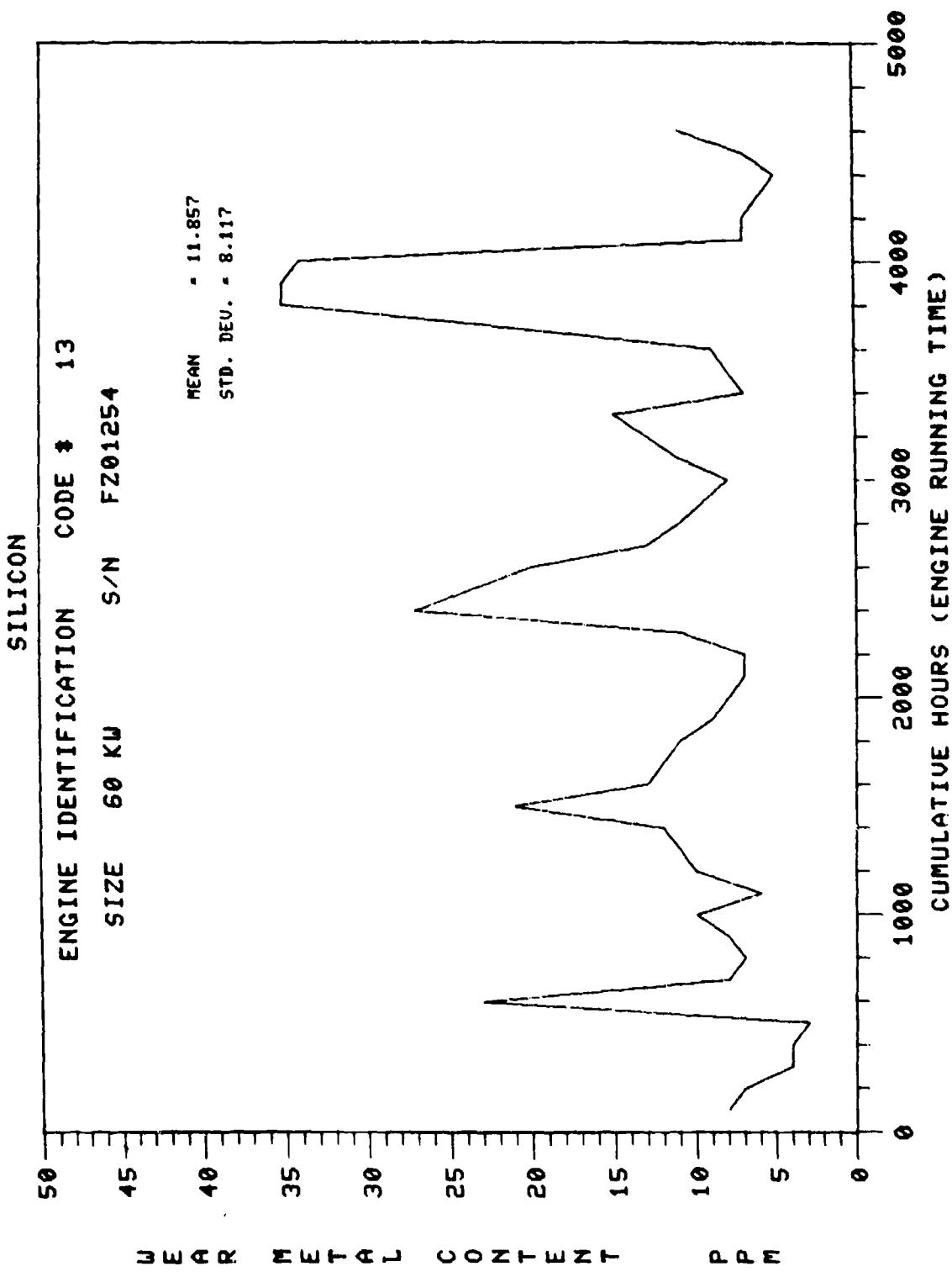
YEAR METAL CONTENT PPM

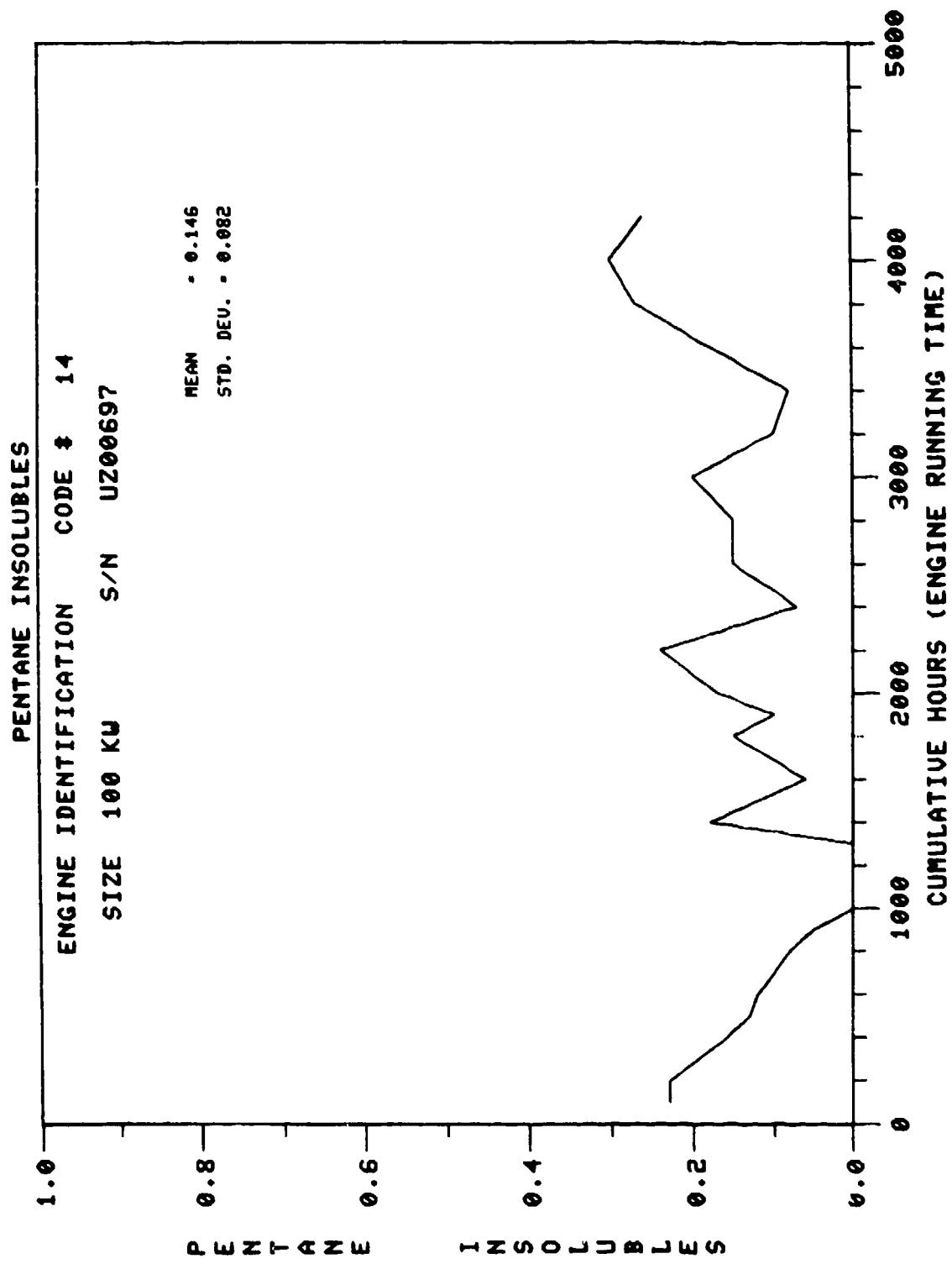
COPPER











VISCOOSITY AT 210 DEGREES F.

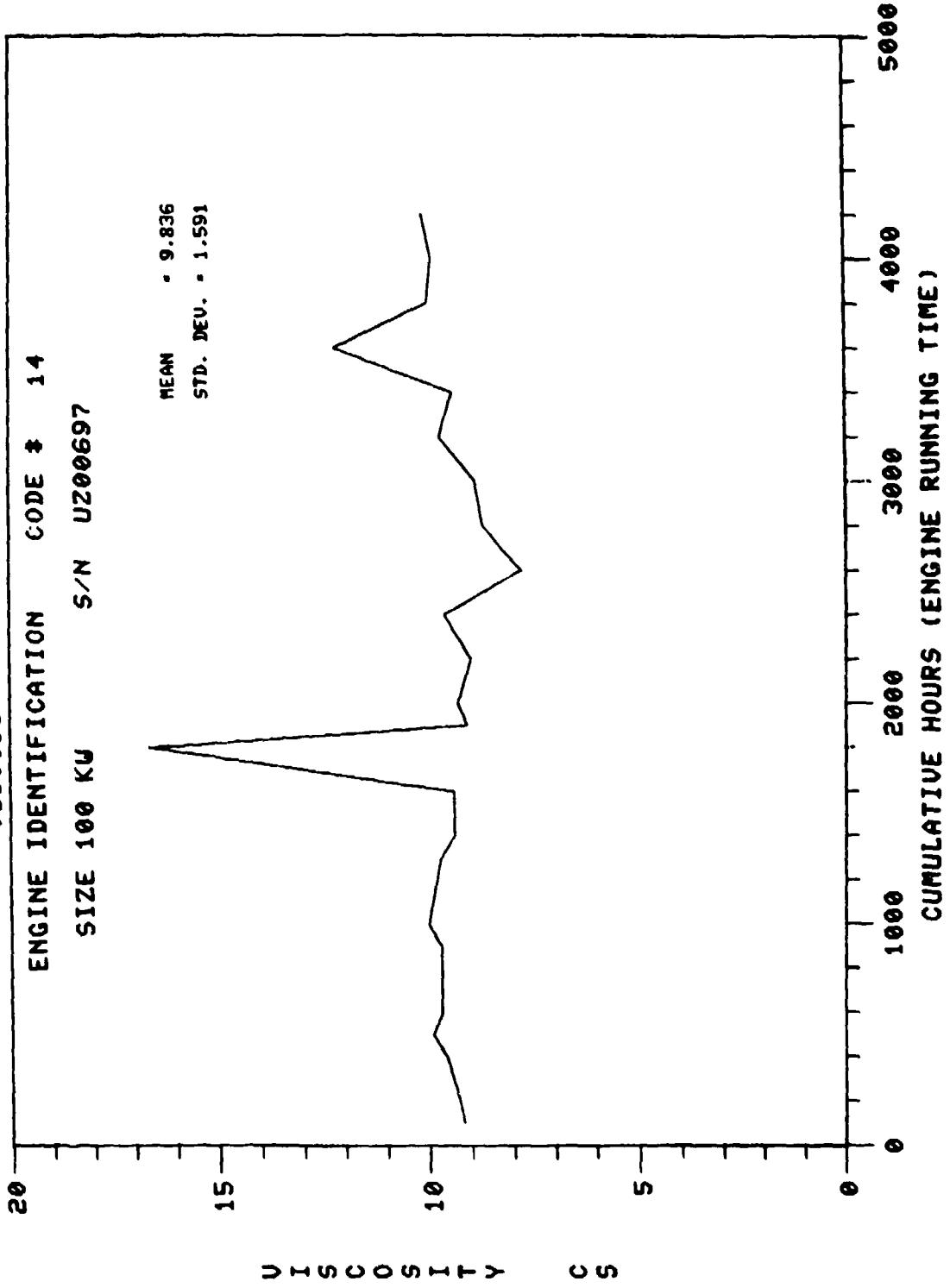
ENGINE IDENTIFICATION CODE # 14

SIZE 100 KU S/N U200697

MEAN = 9.836

STD. DEV. = 1.591

DISCOSITY CS

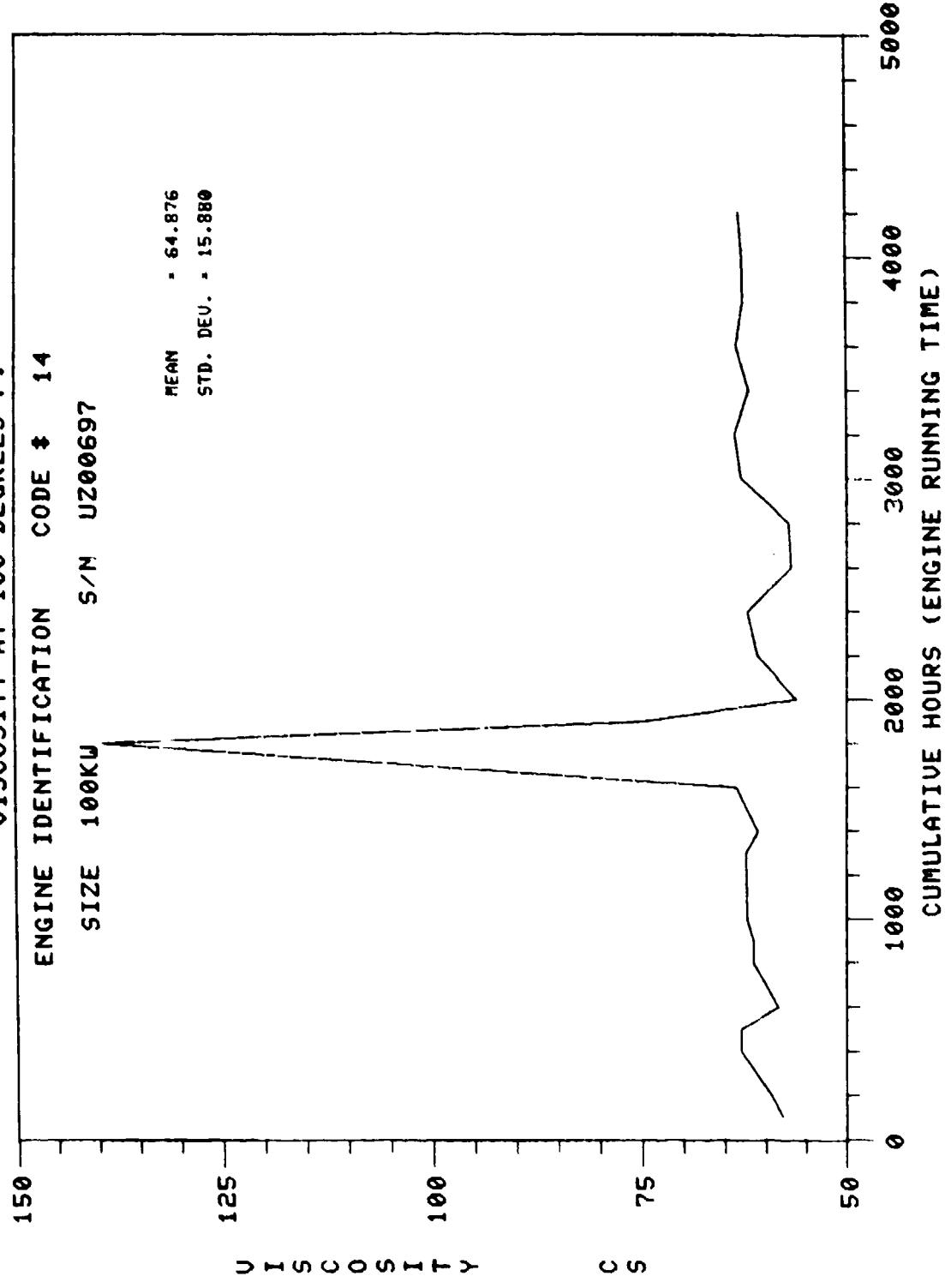


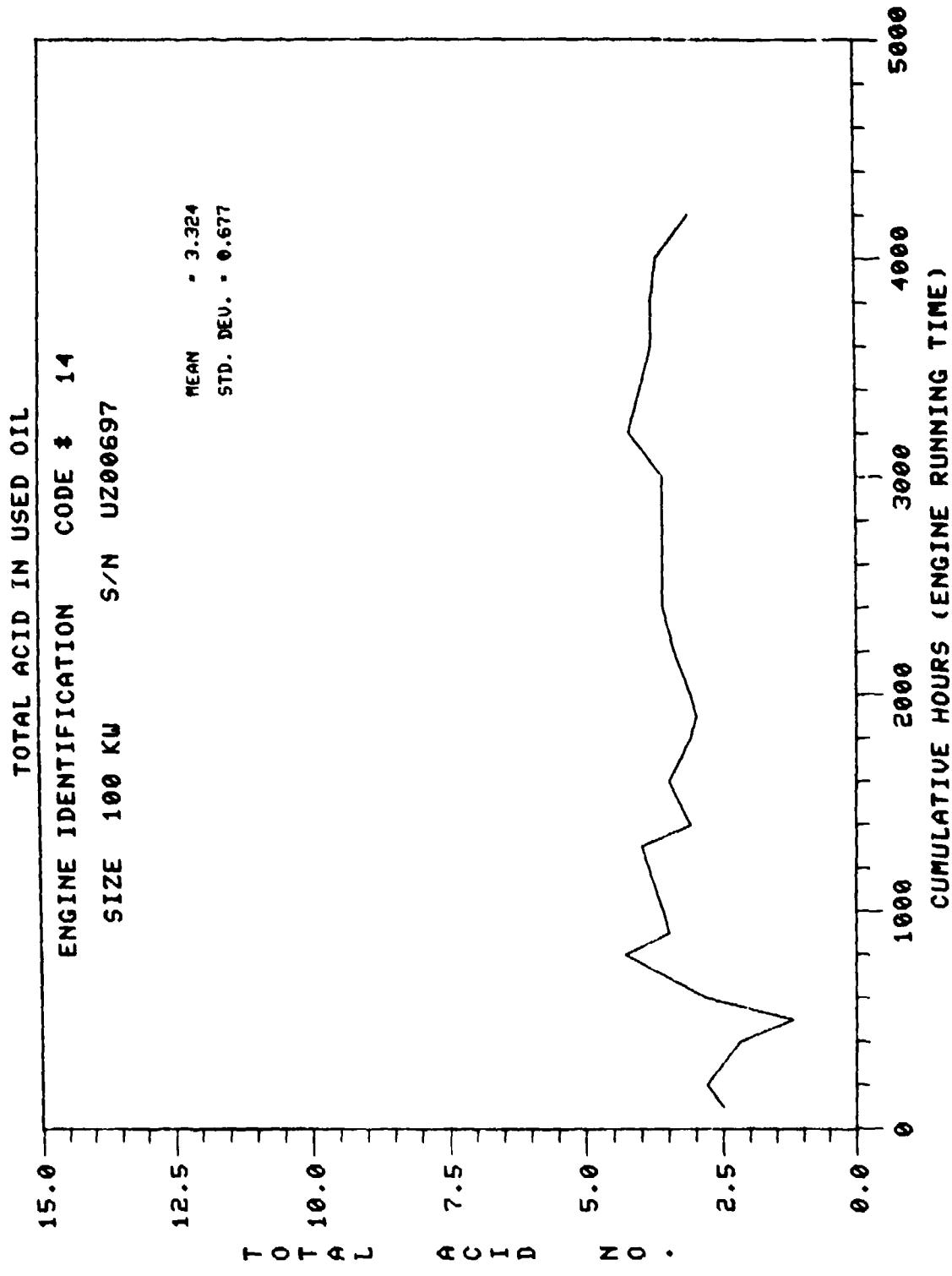
VISCOSEITY AT 100 DEGREES F.

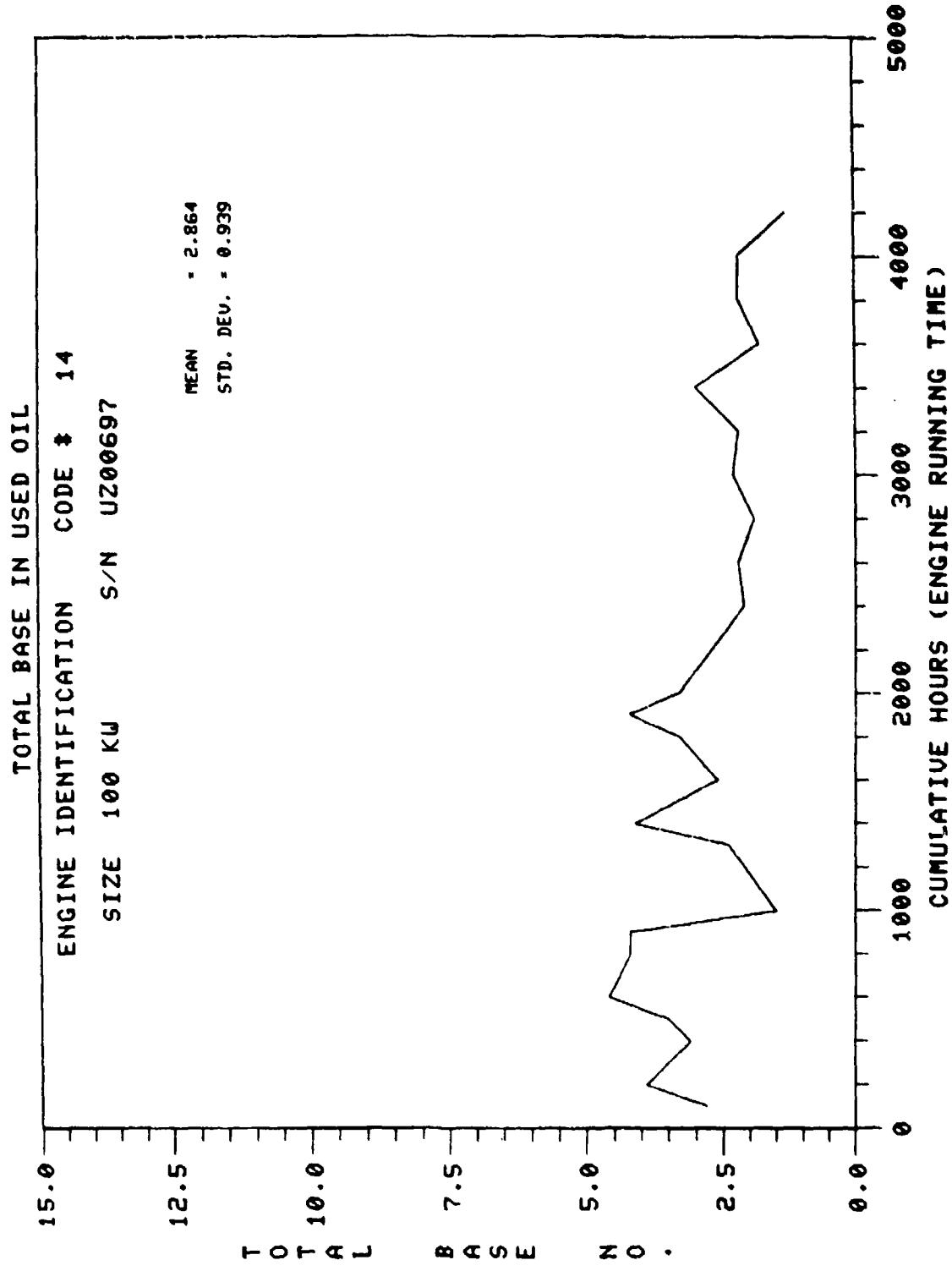
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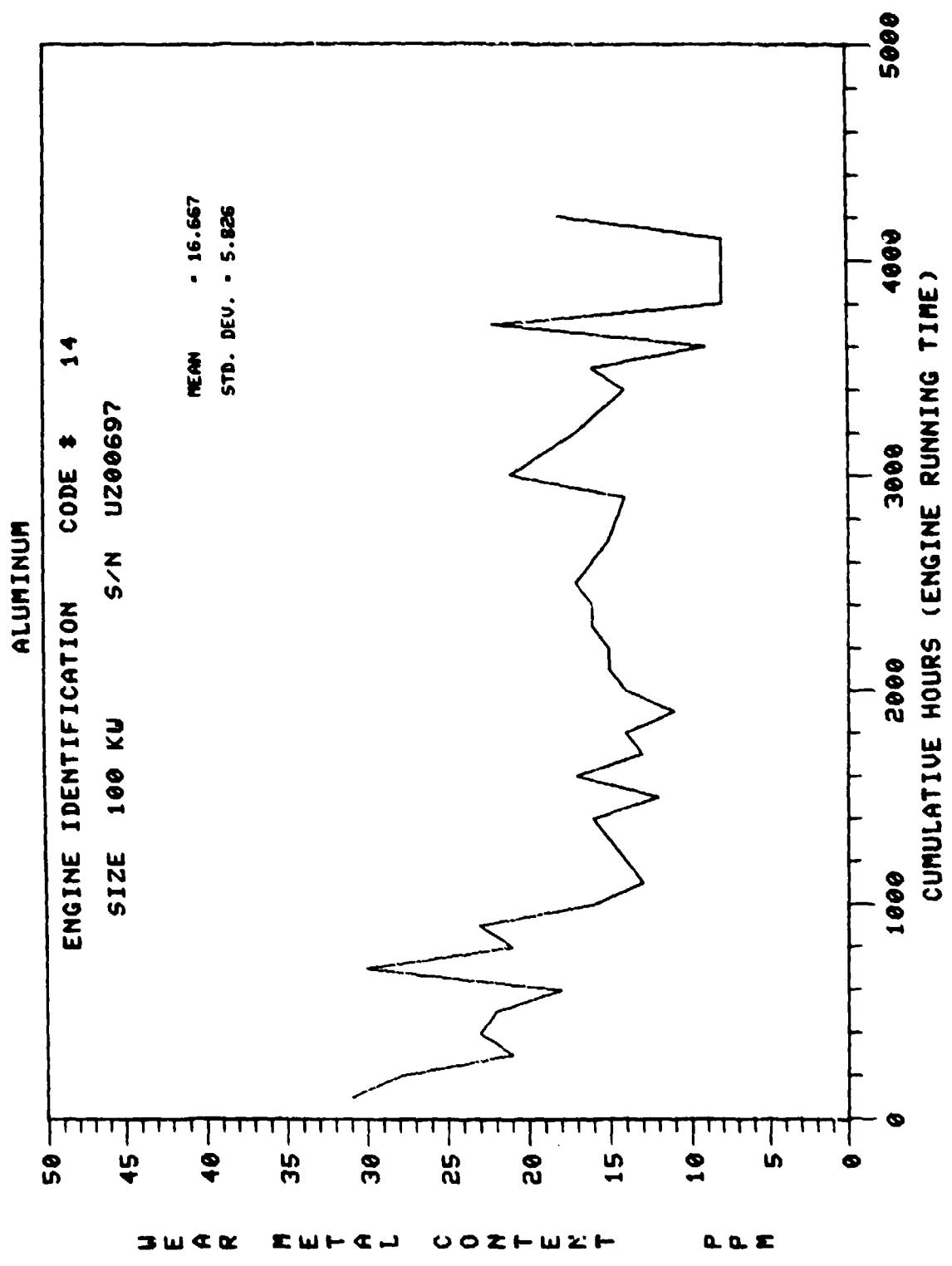
SIZE 100KU S/N UZ00697

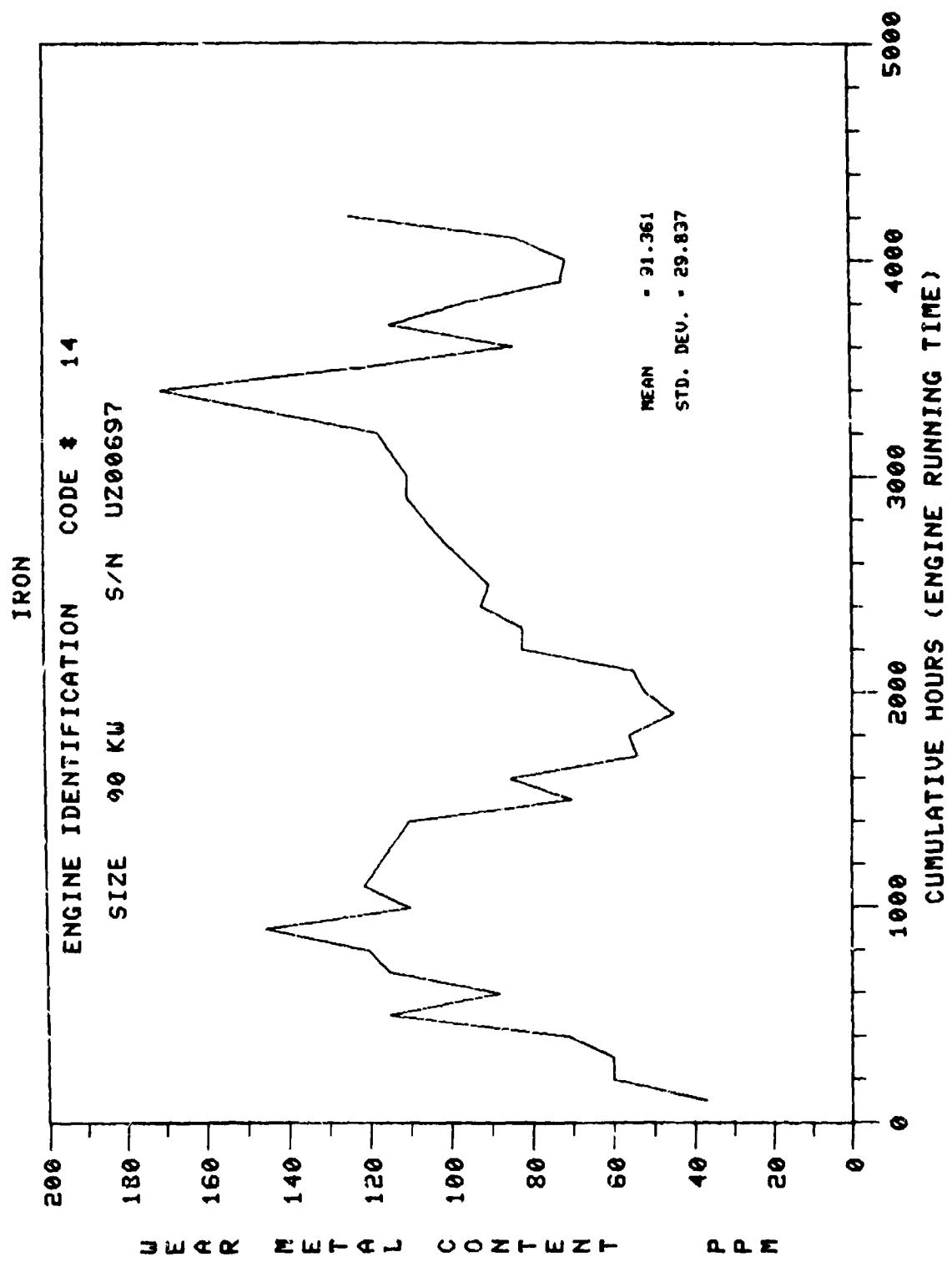
MEAN = 64.876
STD. DEV. = 15.8880



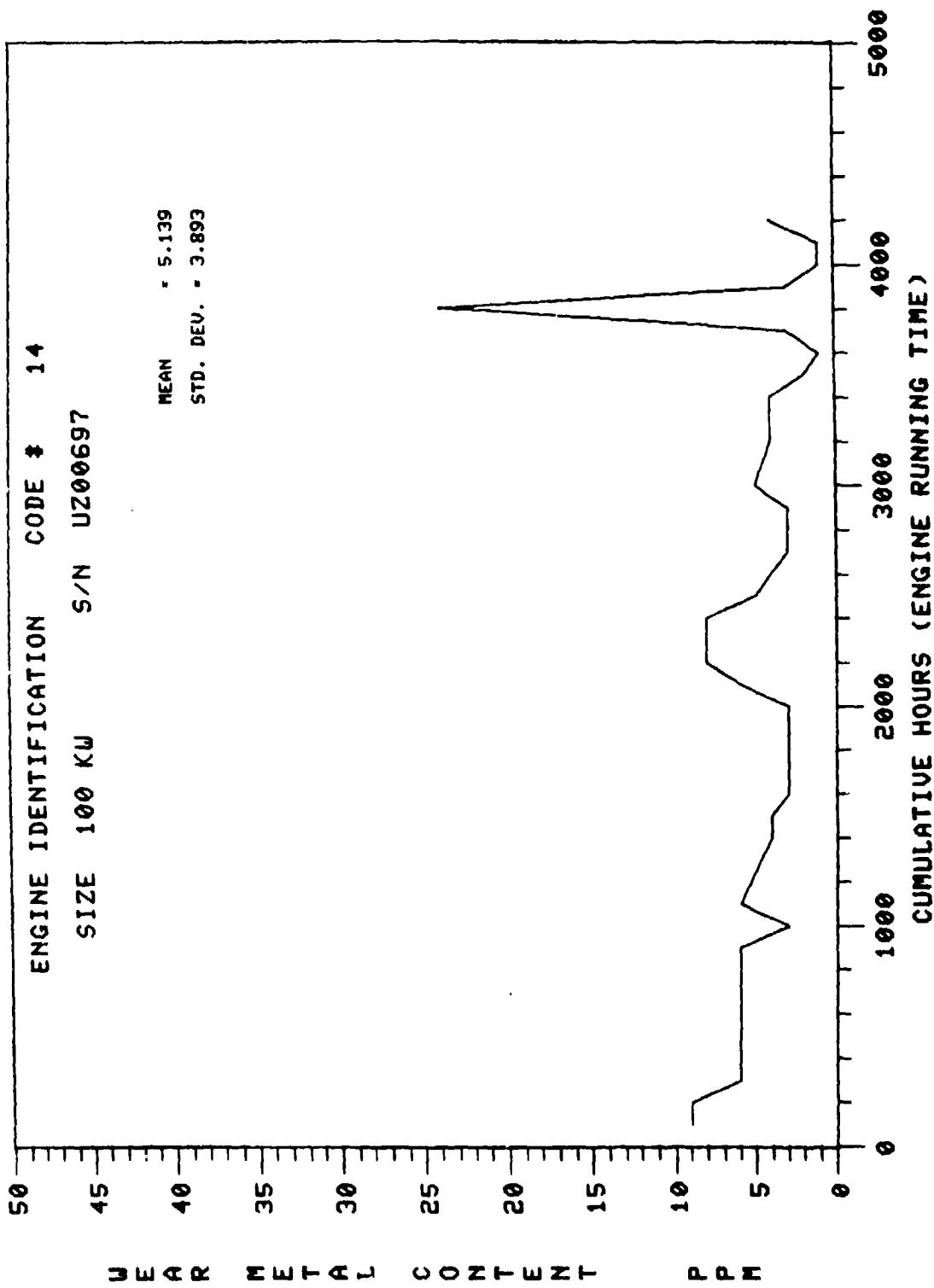




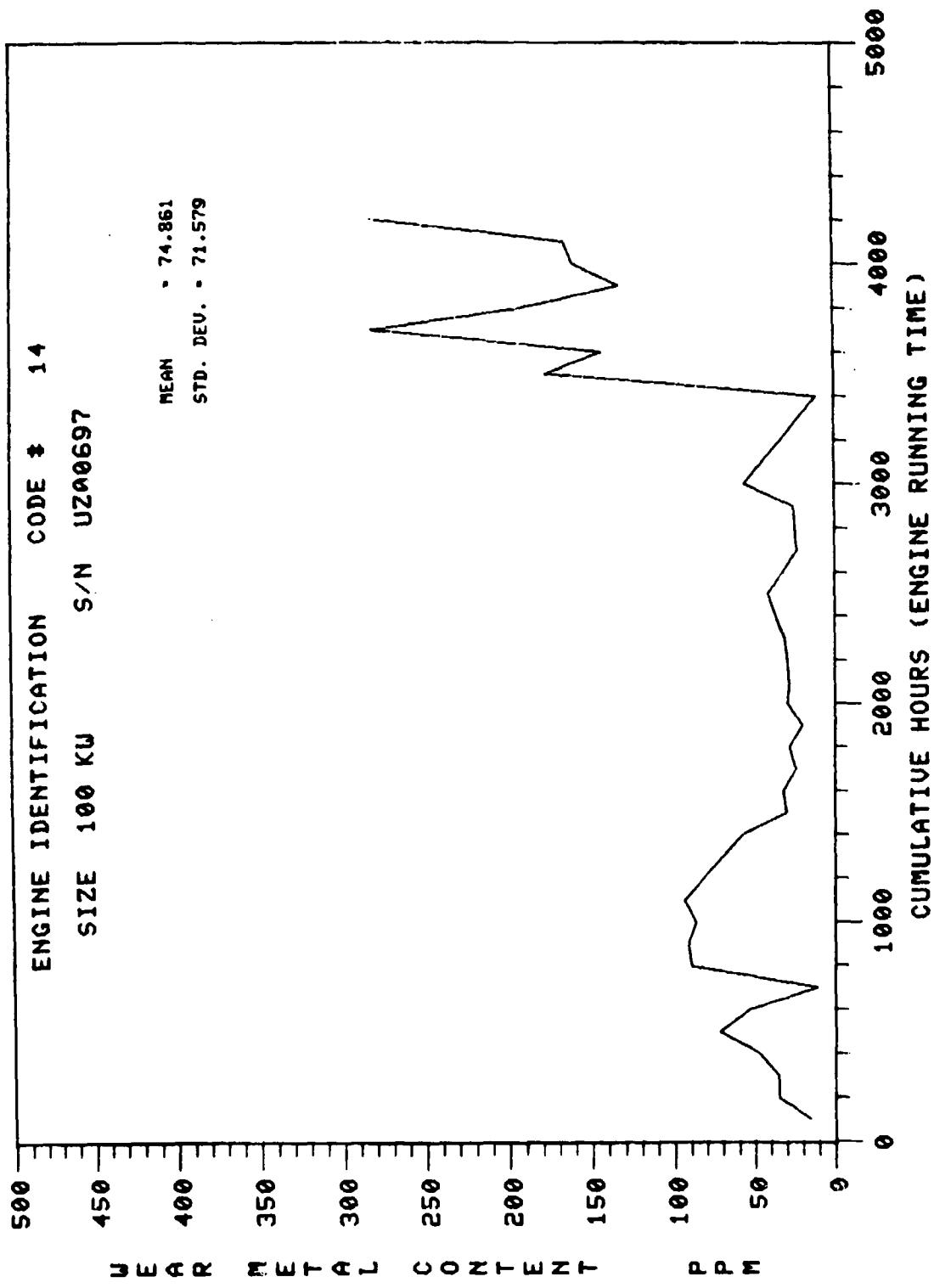


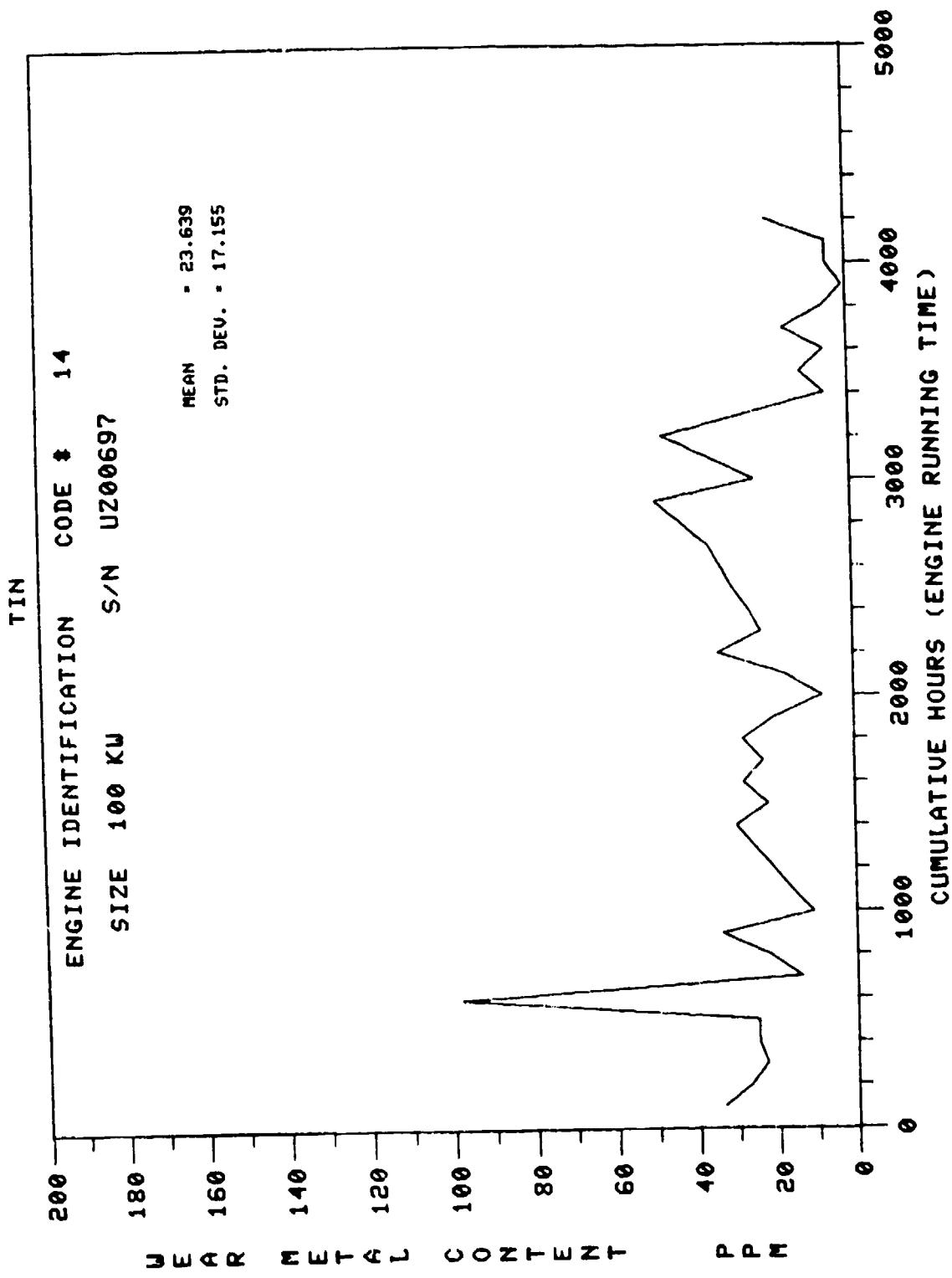


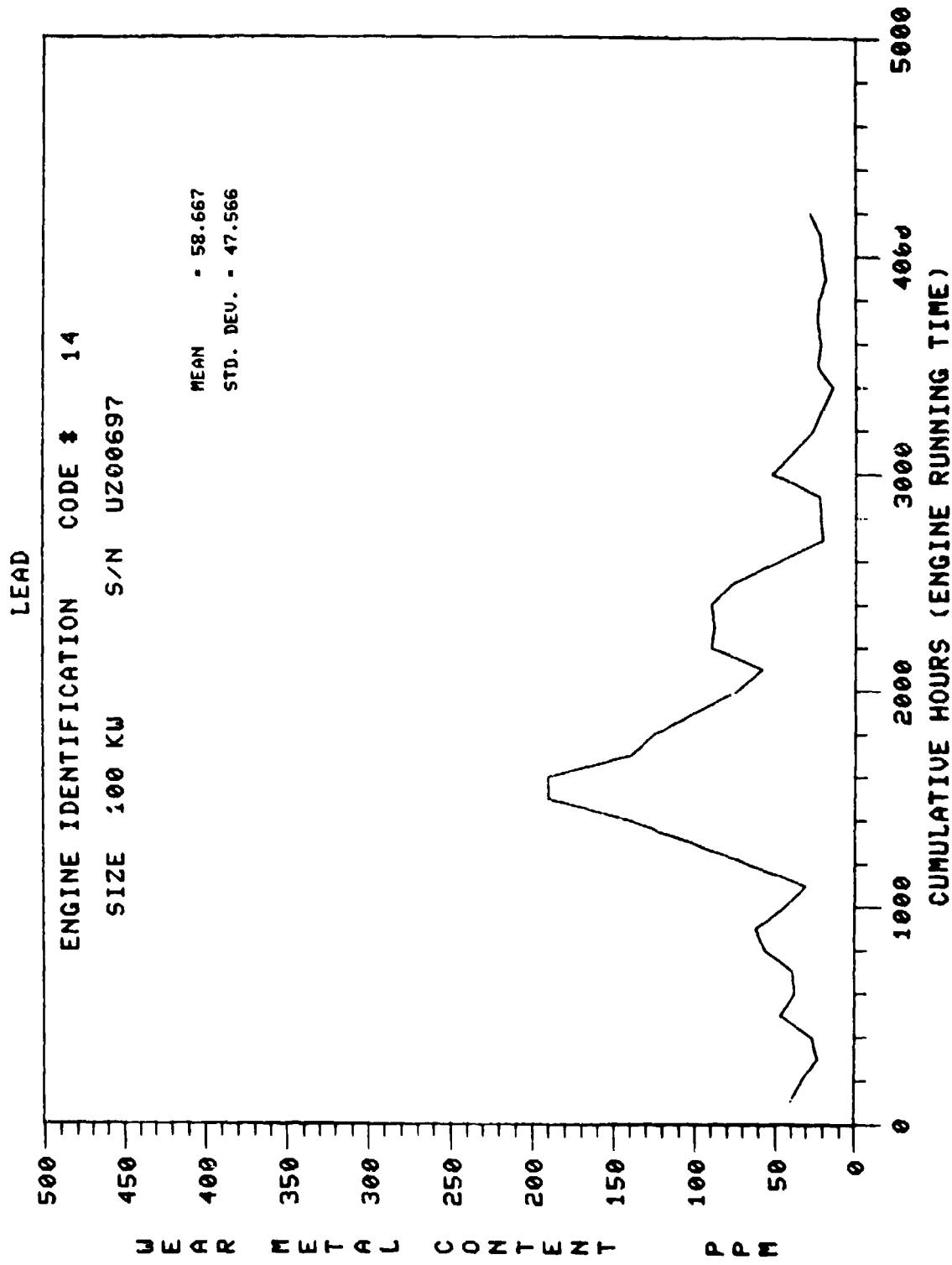
CHROMIUM

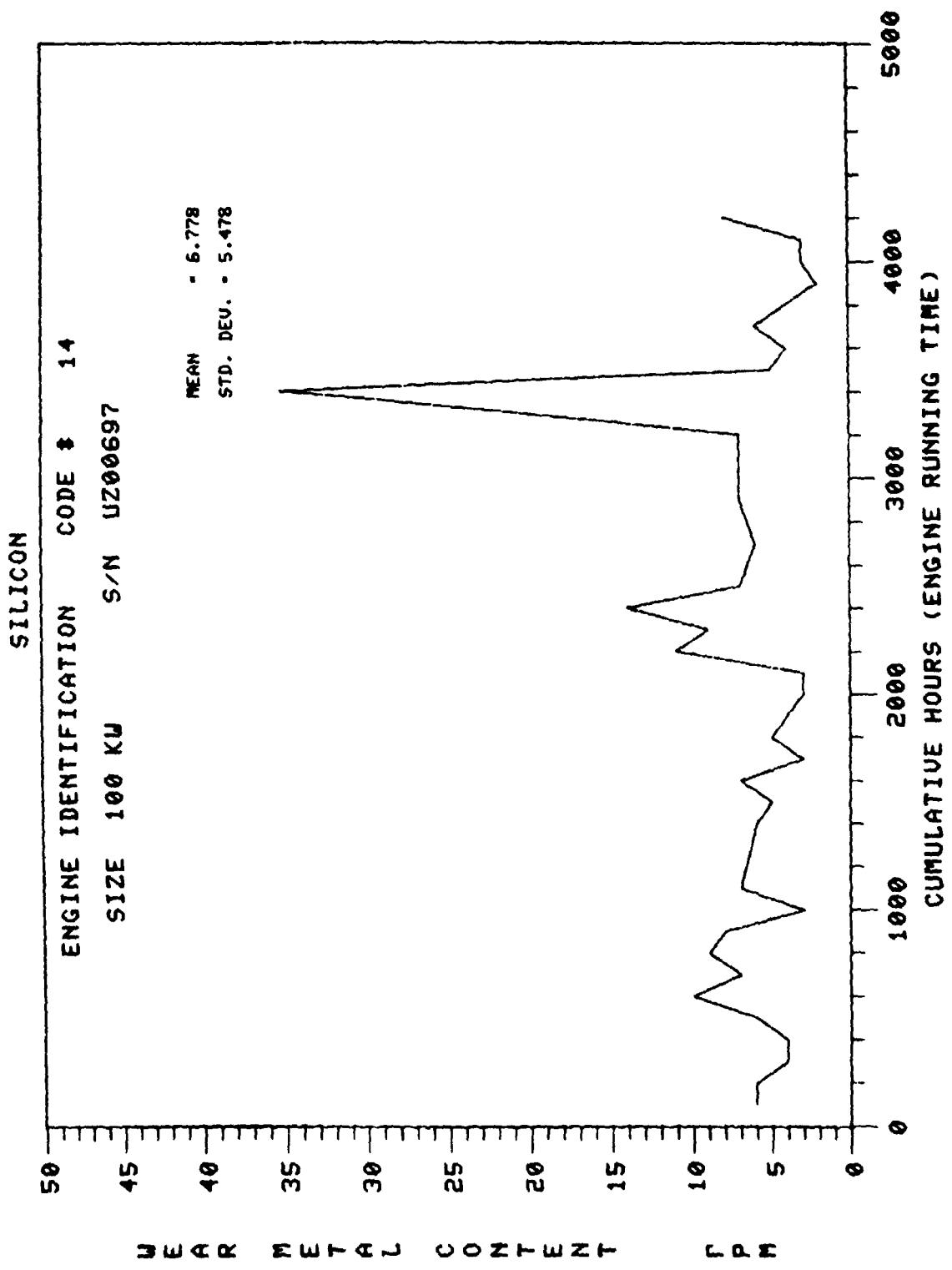


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